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ULTRA-HIGH-MODULUS GRAPHITE/EPOXY CONICAL SHELL DEVELOPMENT

August 1978

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FINAL REPORT

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The work reported herein represents Convair's effort in a program conducted for AMMRC in conjunction with Martin Marietta Aerospace, Orlando Division. The overall objective of the program is to demonstrate by analysis, fabrication, and testing of conical sections of ultra high-modulus graphite/epoxy structures that the material is applicable on future high-performance interceptors. In this cooperative effort Martin Marietta performed detailed design, stress analysis, and testing under AMMRC

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20. Contract DAAG46-75-C-0097 (see Final Report AMMRC CTR 78-4 dated January 1978). Convair Division of General Dynamics assisted in the design and carried out the fabrication development as described herein. GY70/934 epoxy (Fiberite's HY-E-1534) ultra-high-modulus unidirectional tapes were used in construction of the basic shell structure in the subscale development program. Ten subscale conical frusta representing the basic shell were fabricated and supplied to AMMRC. Testing at Martin Marietta confirmed their analytically predicted performance and enabled the program to investigate methods of fabricating strong, stiff end reinforcements for field splicing of missile sections. Twelve subscale cones were fabricated and supplied to AMMRC to evaluate three types of interleaved titanium foil joint concepts. Four cones representing one of these concepts have been successfully tested to date (see AMMRC CTR 78-4).

PREFACE

This final report is prepared by General Dynamics Corporation, Convair Division for the Army Materials and Mechanics Research Center (AMMRC), Watertown, Massachusetts under contract DAAG46-76-C-0008. This work is part of the program on Development of Hardened ABM Materials, Mr. John F. Dignam, Program Manager. The AMMRC Technical Supervisor is Mr. Lewis R. Aronin.

This report covers work from 15 August 1975 to 30 November 1976. The work was performed by personnel from General Dynamics Convair Division under direction of the Materials and Process Engineering Group. Mr. Julius Hertz is the program manager. Mr. Hugh McCutchen, Mr. Gary C. Krumweide, and Mr. Edward E. Spier were responsible for design and analysis functions and Dr. N. Raymond Adsit was responsible for specimen testing. Conical shell test specimens were fabricated by Mr. Charles M. Ogle.

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SECTION 1

SUMMARY

Structural requirements for advanced anti-ballistic missiles (ABM) have continually shown the need for lightweight, high modulus materials. Complementing programs have been performed by General Dynamics Convair Division and Martin Marietta to pursue ultra-high-modulus graphite/epoxy conical shell development. Martin Marietta's program was to experimentally verify design techniques for laminated conical shells fabricated from unidirectional prepreg tapes and to develop reinforcement designs for joints, cut-outs, and attachments in a low-strain composite material subject to shock loadings. The objectives of the Convair program were to develop the processing techniques for conical shells suitable for use in advanced ABM applications, to qualify an ultra-high-modulus graphite/epoxy (GY-70/934) to Material Specification ANA74700314-001, and to assist Martin Marietta in layup selection, joint design, adhesive selection, etc.

A manufacturing process using prepreg gore sections laid into and cured in a bulk graphite female tool was demonstrated for manufacturing graphite/epoxy cone frusta specimens. Ten cones having closely controlled and uniform wall thickness were made in this manner and were successfully tested by Martin Marietta. The results generally met or exceeded analytical predictions. The prepreg used in making the cones, Fiberite HY-E-1534 (GY-70/934), was qualified to specification ANA74700314-001, which was developed by Martin Marietta under AMMRC sponsorship. The prepreg was demonstrated to have a shelf life at 0F exceeding 15 months.

A manufacturing process was also developed for interleaving titanium foils between graphite/epoxy layers in a closed conical shape. Thirteen graphite/epoxy conical frusta specimens having varying interleaved titanium joint designs were successfully built. Four of these have been tested by Martin Marietta, and all have met or exceeded analytical predictions. The titanium foils used in this program were perforated in a set pattern by chemical milling. During cure, the perforations allow resin bleeding and escape of volatiles. This allows uniform wall thickness in the built-up joint areas.

SECTION 2

INTRODUCTION

2.1 BACKGROUND

Structural requirements for advanced anti-ballistic missiles (ABM) have continually shown the need for lightweight, high-modulus materials. System studies performed by Martin Marietta under Contracts DAAHC-60-72-C-0022 and DASG 60-75-C-0043 highlighted the advantages of ultra-high-modulus graphite/epoxy and beryllium structures. The results of these studies have shown that ultra-high-modulus graphite/epoxy primary structure will provide a significant launch weight reduction over more conventional materials.

Complementing programs have been performed for the Army Materials and Mechanics Research Center by Martin Marietta (Contract DAAG46-75-C-0097) and General Dynamics Convair Division (Contract DAAG46-76-C-0008) to pursue the ultra-high-modulus graphite/epoxy conical shell development.

The primary objective of Martin Marietta's Subscale Conical Shell Development program was to demonstrate the feasibility of ultra-high-modulus graphite/epoxy structures for advanced ABM applications. The secondary objectives were: 1) to experimentally verify design techniques for laminated conical shells fabricated from unidirectional prepreg tapes, and 2) to develop reinforcement designs for joints, cutouts, and attachments in a low-strain composite material under shock loadings

GY-70 was selected as the ultra-high-modulus graphite fiber for the Subscale Conical Shell Development program because of cost advantage and availability. GY-70 is a product of Celanese Corporation of Summit, New Jersey. The preimpregnated unidirectional tape, GY-70/934, used in the fabrication of the conical shells was purchased from Fiberite Corporation of Winona, Minnesota.

The scope of work for General Dynamics' program is detailed below. The primary objective of General Dynamics' program was to develop the processing techniques for conical shells suitable for use in advanced ABM applications. Secondary objectives were to qualify GY-70/934 prepreg to the AMMRC material specification as shown in Appendix A (same as Martin Marietta specification ANA74700314-001) and to assist Martin Marietta in layup selection, joint design, etc.

2.2 SCOPE OF WORK

2.2.1 Fabricate 10 Conical Frusta

2.2.1.1 Construction: Graphite/epoxy multiple layup construction with aluminum ring reinforcements at both ends per Martin Marietta Drawing 48125D (Figure 4-1).

2.2.1.2 Materials: GY-70/934 graphite/epoxy prepreg supplied by Fiberite Corporation.

2.2.1.3 Prepreg to be procured in accordance with AMMRC specification.

2.2.1.4 Materials shall be procured in single lots to insure uniformity of fabricated parts.

2.2.1.5 Contractor shall perform acceptance testing on prepreg materials to substantiate physical and mechanical properties and quality control requirements per AMMRC material specification.

2.2.1.6 First five frusta to be fabricated in accordance with Drawing 48125. A second lot of five frusta shall be subject to modification to incorporate mutually agreed upon changes in layup design or fabrication procedures based on Contractor recommendations and on results of analysis and test results furnished by AMMRC.*

2.2.2 Fabricate Six Type 1 Conical Frusta with Joint Reinforcements

2.2.2.1 Construction: Graphite/epoxy multiple layup construction with end reinforcements per Drawing 48126 (Figure 4-19).

2.2.2.2 Recommendations of the Contractor will be considered in the choice of materials, design, and fabrication procedures. Final selection will be agreed upon between the Contractor and the Government Contracting Officer's Representative.

2.2.2.3 Materials: Fiberite GY-70/934 graphite/epoxy prepreg for the frusta shall conform to the requirements set forth in 2.2.2.1 above. End reinforcement shall consist of interleaved titanium foil per Martin Marietta joint design No. 1 (Drawing 48126).

2.2.3.1 Construction: Graphite/epoxy multiple layup construction with end reinforcements per Drawing 48126 (Figure 4-19).

2.2.3.2 End reinforcements shall consist of interleaved titanium foil per Martin Marietta joint design No. 2 (Drawing 48126).

* As discussed in Section 4 of this report, the second lot of five frusta were actually fabricated to the same design as the first five because their performance proved satisfactory.

2.2.3.3 Recommendations of the Contractor will be considered in the choice of materials, design, and fabrication procedures. Final selections will be agreed upon between the Contractor and the Government Contracting Officer's Representative.

2.2.3.4 Materials: Celanese GY-70 graphite reinforced epoxy prepreg for the frusta shall conform to the requirements set forth in Paragraph 2.2.1.3 above.

2.2.4 Fabricate Three Conical Frusta Type 3 with Joint Reinforcements

2.2.4.1 Construction: Graphite/epoxy multiple layup construction with end reinforcements per Drawing 48126 (Figure 4-19).

2.2.4.2 End reinforcements shall be interleaved titanium foil per Martin Marietta joint design No. 3 (Drawing 48126).

2.2.4.3 Recommendations of the Contractor will be considered in the choice of materials, design, and fabrication procedures. Final selection will be agreed upon between the Contractor and the Government Contracting Officer's Representative.

2.2.4.4 Materials. Celanese GY-70 graphite reinforced epoxy prepreg for the frusta shall conform to the requirements set forth in 2.2.1.3 above.

2.2.5 Consultation. The Contractor shall provide an interactive technical consultation with the Government and designated Government contractors with respect to design and producibility of the specimens and structures required under Paragraphs 2.2.1 through 2.2.4.

2.2.6 Process Documentation: Documentation shall be developed for all the materials, processes, and procedures employed in the fabrication of parts and specimens under this contract. This shall include all materials handling, tooling, material, fabrication and layup, curing, machining, inspection, and quality control. Contractor shall ensure an adequate photographic record of fabricated parts and processes.

SECTION 3

PREPREG QUALIFICATION

On initiation of this program, 200 pounds of GY-70/934 (Fiberite's HY-E-1534) prepreg was ordered from Fiberite Corporation of Winona, Minnesota. The prepreg was ordered per Martin Marietta material specification ANA74700314-001 (see Appendix A) with the following exceptions and additions: nominal slit width was 2.75 in. and coefficient of variation requirements of the specification were waived. In August 1975, when the program began, there was a shortage of GY-70 fibers and a projected delivery of eight weeks for all new orders. As a result of discussions, prior to contract award, with the Celanese Corporation of Summit, New Jersey, 50 pounds of fiber had been set aside for the support of the Graphite/Epoxy Conical Frusta program. These fibers were in non-standard weight rolls, i.e., 1.8 pounds rather than 2.0 pounds, etc.

The 50 pounds of fiber was shipped immediately to Fiberite, and they in turn attempted to prepreg the fiber. Fiberite encountered prepregging difficulties with much of the fiber because of disintegration of the cross threads on the GY-70 fiber tape. Of the 50 pounds, only 25% was of recent vintage, and this may account for Fiberite's difficulties. From the first fiber shipment, Fiberite successfully prepared about 21 pounds of prepreg tape (lot 4D-94) that met the acceptance requirements of ANA74700314-001. About half of this prepreg was used for qualification testing.

Fiberite's certification test data on prepreg lot 4D-94 is summarized in Table 3-1. Prepreg roll number 9 was selected for qualification testing, and a summary of prepreg property test results is given in Table 3-2. The average of all properties was within the specification limits. An infrared curve was run per the material specification and is shown as Figure 3-1.

Four test panels were prepared conforming to the requirements specified in Tables V and VII of Appendix A and were used for thickness and mechanical property determinations. Fiberite's recommended cure cycle and prepreg-to-bleeder ratio were utilized. The cure cycle consisted of applying full vacuum at room temperature (RT), holding approximately 30 minutes, raising temperature to 250F at approximately 3F/min, holding at 250 to 260F for 40 to 50 minutes, applying 95 to 105 psig autoclave pressure, holding for 40 to 50 minutes, raising temperature to 350F at approximately 3F/min, holding at 350 to 360F for a minimum of two hours, cooling under vacuum and pressure to below 175F, venting, and debagging. All panels were made using cork dams (around the periphery of the layup) and perforated caul plates (0.063 in. dia. holes on 1.0-in. centers). The thickness panel was of $[0/90/0/90]_S$ orientation, and two plies of 120 style cloth and two plies of 7581 style glass cloth were used for the bleeder. The panel

used for longitudinal tensile specimens was of $[0]_6$ orientation, and two plies of 7581 style glass cloth were used for the bleeder. The remainder of the mechanical property testing was conducted on specimens cut from $[0]_{16}$ panels, and the bleeder system for preparation of the panels consisted of one ply of 120 and five plies of 7581 style glass fabrics. The vacuum bagging material in all cases was Vac-Pak H.S.-8171 nylon base film obtained from Richmond Division of Pak-Well, Los Angeles, California.

Test results on longitudinal flexure, transverse flexure, and short beam shear on panels made from roll number 9 are summarized in Table 3-3. The results failed to meet specification requirements for RT longitudinal flexure strength, RT and 350F longitudinal flexure modulus, and RT and 350F transverse flexure strength. Two longitudinal tensile specimens were tested at RT and gave average values of 87.5 ksi and 39.6 msi respectively for strength and modulus. The most disturbing results were the very low longitudinal flexure strengths. Fiberite was contacted, but they could shed no light on why Convair's results were so much lower than Fiberite's (see Table 3-1). It was learned that their data was obtained on panels made from prepreg roll number 1.

Convair prepared four test panels as above from prepreg roll number 1. Results on flexure and shear testing are given in Table 3-4. The longitudinal flexure and short beam data more nearly approach results obtained by Fiberite. Only the RT longitudinal flexure modulus is below specification requirements. Longitudinal and transverse tensile data are summarized in Tables 3-5 and 3-6. Strain gages were used to obtain load versus strain data from which modulus values were calculated. The longitudinal strengths and moduli at RT and 350F greatly exceed the requirements of the material specification. The coefficients of variation (V) for longitudinal strength at both temperatures exceeded the 7.5% maximum of the A version of the material specification.* This was anticipated based on prior Convair experience, and was the reason for waiving these requirements on the purchase of the prepreg material. Modulus values have always been very consistent, and this is confirmed by the very low coefficient of variations obtained in the qualification testing. Transverse tensile strengths obtained were borderline at RT but failed to meet the 350F requirement of the material specification. Transverse moduli values greatly exceeded the specification requirements. The coefficient of variation values for transverse tensile properties, when rounded off, met the specification requirements. The 350F transverse tensile strength requirement appears totally unrealistic for a non-postcured laminate.

Panels were made from the remaining rolls of the first prepreg shipment, and specimens cut from these panels were tested in flexure. The results are summarized in Table 3-7. The values for strength were consistent and significantly higher than the minimum specification requirement of 95 ksi. The modulus values were consistent for each panel but the averages varied from 34.1 to 37.6 msi for the five panels. This confirmed that the minimum specification value of 36.0 msi as specified in the A version was unrealistic and should probably be 34.0 msi. This has been corrected in ANA74700314-001B (see Appendix A).

* This has been corrected in the B version. See Appendix A, Table IV.

The thickness panel was prepared per the material specification, and the resulting measurements gave an average cured ply thickness of 4.95 mils. Thermal expansion measurements were made on both 0° and 90° specimens cut from panel AMMRC-2R. The specimens were run from RT to 350F using a Leitz dilatometer. The average coefficient of expansion for the 0° specimen was -0.47 μ-in./in.°F. For the 90° specimen, the average coefficient of expansion was 18.6 μ-in./in.°F. The plots of expansion data are shown in Figures 3-2 and 3-3.

Table 3-1. Fiberite Certification Data on HY-E-1534, Batch 4D-94

Quantity Shipped on 9/17/75	21.3						
Lot No.	4D-94						
Roll No.	1	3	5	6	8	9	10
Tape Size, Inches	2.75	2.75	2.75	2.75	2.75	2.75	2.75
Resin Solids, %	40.3	39.3	37.0	38.1	37.0	37.6	40.1
Volatile Content, %	1.0	0.9	0.9	1.0	0.8	0.8	0.6
Laminate Flow, % @ 100 psi	15.4	17.4	17.2	17.9	19.3	17.2	15.4
Gel Time, Minutes 180F	203.0	202.0	217.8	236.2	218.0	198.0	203.1
250F	45.8	52.2	50.0	69.1	48.8	50.1	55.1
350F	7.1	8.7	8.9	9.0	8.8	9.3	9.0

Fiber Volume, %	67.86	
Resin Content, %	23.9 (Cured Panel)	
Resin Type	Type A (Fiber sizing is compatible with the resin system used)	
Void Content	0.453	
Flexural Strength (psi)	*RT = 134,817 *350F = 124,810	*Values Normalized to 63% Fiber Volume.
Flexural Modulus (10^6 psi)	*RT = 36.22 *350F = 38.15	Fiber Properties Per Attached.
Horizontal Beam Shear (psi)	RT = 7,315 350F = 6,668	The prepreg tow, when laminated into unidirectional specimens, shall possess the properties required in Table IV of subject specification.
Cured Ply Thickness, Inches	0.00475	The raw material and process used in manufacturing of the finished product have not been changed.
Date of Manufacture	9/9/75	
Shelf Life	6 months at 0F Max.	

Table 3-1. Fiberite Certification Data on HY-E-1534, Batch 4D-94, Contd

Fiber Data

Lot No. ST/4-113		
Bobbin No. =	5	
Tensile Strength, (ksi) =	274	
Tensile Modulus, (msi) =	73.7	
Density, (gm/cc) =	1.96	
Lot No. ST/3-114		
Bobbin No. =	18 & 19	31
Tensile Strength, (ksi) =	270	308
Tensile Modulus, (msi) =	75.5	77.9
Density, (gm/cc) =	1.95	1.95
Lot No. ST/3-116		
Bobbin No. =	21	28 & 37
Tensile Strength, (ksi) =	263	277
Tensile Modulus, (msi) =	70.1	76
Density, (gm/cc)	1.96	1.97
Lot No. ST/4-117		
Bobbin No. =	1	14
Tensile Strength, (ksi) =	312	300
Tensile Modulus, (msi) =	73.6	70.4
Density, (gm/cc) =	1.94	1.97
Lot No. ST/4-115		
Bobbin No. =	9	
Tensile Strength, (ksi) =	273	
Tensile Modulus, (msi) =	70.9	
Density, (gm/cc) =	1.96	

Table 3-2. Convair Results on Prepreg Testing (Lot 4D-94 Roll No. 9)

	Resin Flow (%)	Volatiles (%)	Resin Solids (%)	Drape	Tack	Gel Time At 180F (min)	Gel Time At 280F (min:sec)	Gel Time At 350F (min:sec)
	20.9	0.08	36.3	Passed	Passed	230	34:24	5:50
	18.2	0.03	37.1	Passed	Passed	230	34:40	5:50
	17.3	0.05	37.9	Passed	Passed	230	34:40	5:50
Average	18.8	0.05	37.1			230	34:35	5:50
Spec. Req.	20 ± 5	2.0 max.	40 ± 3	Pass	Pass	To be reported per specification.		

Table 3-3. Test Results on Qualification Panel AMMRC-1 (Prepreg Lot 4D-94, Roll No. 9)

Temperature	Longitudinal Flexure Strength (ksi)	Longitudinal Flexure Modulus (msi)	Transverse Flexure Strength (ksi)	Transverse Flexure Modulus (msi)	Short Beam Shear Strength (ksi)	Specific Gravity	Resin Content (Wt. %)	Fiber Volume (%)
RT	93.4	33.8	5.64	1.1	8.0	1.724	26.95	64.26
	94.0	34.1	6.57	1.3	6.6	1.726	27.26	63.90
	87.1	32.4	4.55	1.2	5.9	1.724	27.84	63.23
	93.0	31.7	5.22	1.2	6.5	1.725	27.35	63.80
	89.7	32.6	5.07	1.1	6.2			
Average	91.4	32.9	5.29	1.2	6.6			
Normalized to 63% F.V.	90.3	32.5						
Min. Specification Requirements	95.0	36.0	6.0	0.6	6.0			
350F	100.0	31.8	3.48	0.72	6.0			
	94.8	32.1	4.38	0.84	4.8			
	101.0	32.1	3.50	1.10	5.9			
	96.4	—	3.53	1.10	6.1			
	90.9	33.3	3.72	1.22	6.6			
Average	96.6	32.3	3.72	1.00	5.9			
Normalized to 63% F.V.	95.4	31.9						
Min. Specification Requirements	95.0	35.0	4.0	0.5	4.0			

Table 3-4. Test Results on Qualification Panel AMMRC-1R (Prepreg Lot 4D-94, Roll No. 1)

Temperature	Longitudinal Flexure Strength (ksi)	Longitudinal Flexure Modulus (msi)	Transverse Flexure Strength (ksi)	Transverse Flexure Modulus (msi)	Short Beam Shear Strength (ksi)	Specific Gravity	Resin Content (Wt. %)	Fiber Volume (%)
RT	115.9	34.8	6.3	1.02	7.6	1.722	28.06	62.97
	118.5	35.4	6.6	1.20	7.9	1.716	27.82	63.04
	126.3	34.5	6.4	1.12	7.7	1.716	27.62	63.48
	120.5	34.2	5.7	1.39	7.8	1.718	27.83	63.15
	121.7	34.9	6.4	1.12	7.9			
Average	120.6	35.0	6.3	1.17	7.8			
Normalized to 63% F.V.	120.3	34.9						
Min. Specification Requirements	95.0	36.0	6.0	0.6	6.0			
350F	110.0	35.3	4.3	0.96	7.2			
	102.4	36.1	4.6	1.07	7.0			
	105.3	36.1	3.7	1.07	7.1			
	103.0	36.1	4.1	1.06	6.8			
	96.6	34.4	3.1	1.05	6.9			
Average	103.5	35.6	4.0	1.04	7.0			
Normalized to 63% F.V.	103.3	35.5						
Min. Specification Requirement	95.0	35.0	4.0	0.5	4.0			

Table 3-5. Longitudinal Tensile Data on Unidirectional GY-70/934 Test Specimens (Panel AMMRC-3R)

Spec No.	Test Temp.	Width (in.)	Thickness (in.)	Area (in.^{2})	Ult. Load (lb)	Long. Strength (ksi)	Long. Modulus (msi)	Resin Content (Wt. %)	Fiber Volume (%)
I-2540	RT	0.5018	0.0283	0.0142	1630	114.8	44.4		
I-2541	RT	0.4993	0.0281	0.0140	1800	128.6	45.7		
I-2542	RT	0.5011	0.0285	0.0143	1375	92.2	44.8	29.61	61.19
I-2543	RT	0.5012	0.0281	0.0141	1695	120.2	45.4	29.18	61.68
I-2544	RT	0.4977	0.0282	0.0140	1695	121.1	45.0	29.46	61.36
						$\overline{X}$ = 115.4	45.1	29.42	61.41
						V = 12.0%	1.1%		
		Normalized to 63.0% F.V.,				$\overline{X}$ = 118.4	46.3		
		Specification requirements:				$\overline{X}$ = 80 min.	37.0 min.		
						V^* = 7.5% max.	7.5% max.		
I-2550	350F	0.4965	0.0290	0.0143	1958	136.9	49.0		
I2551	350F	0.5002	0.0293	0.0147	1600	108.8	45.6		
I-2552	350F	0.4986	0.0285	0.0142	1540	108.5	47.9		
I-2553	350F	0.5010	0.0283	0.0142	1740	122.5	50.0		
I-2554	350F	0.5001	0.0286	0.0143	1742	121.8	47.6		
						$\overline{X}$ = 119.7	48.0		
						V = 9.8%	3.4%		
		Normalized to 63.0% F.V.				$\overline{X}$ = 112.8	49.2		
		Specification requirements:				$\overline{X}$ = 80 min.	36.0 min.		
						V^* = 7.5% max.	7.5% max.		

* Per ANA74700314-001A. See Appendix A, Table IV for revised requirements.

Table 3-6. Transverse Tensile Data on Unidirectional GY-70/934 Test Specimens (Panel AMMRC-2R)

Spec. No.	Test Temp.	Width (in.)	Thickness (in.)	Area (in.^{2})	Ult. Load (lb)		Trans. Strength (ksi)	Trans. Modulus (msi)	Resin Content (Wt. %)	Fiber Volume (%)
I-2545	RT	0.5008	0.0752	0.0377	167		4.43	0.99		
I-2546	RT	0.4982	0.0750	0.0374	168		4.49	0.99		
I-2547	RT	0.4988	0.0750	0.0374	179		4.79	1.02	29.19	61.67
I-2548	RT	0.4990	0.0740	0.0370	181		4.89	1.01	28.25	62.75
I-2549	RT	0.4983	0.0748	0.0372	139		3.74	1.02	29.07	61.85
						$\overline{X}$ =	4.47	1.01	28.84	62.08
						V =	10.1%	1.5%		
			Specification requirements:			$\overline{X}$ =	4.5 min.	0.5 min.		
						V =	10% max.	7.5% max.		
I-2555	350F	0.4986	0.0734	0.0366	98		2.68	0.85		
I-2556	350F	0.5007	0.0754	0.0377	96		2.55	0.82		
I-2557	350F	0.0746	0.0372	0.0372	92		2.47	0.81		
I-2558	350F	0.5006	0.0750	0.0375	88		2.35	0.83		
I-2559	350F	0.4985	0.0750	0.0374	108		2.89	0.86		
						$\overline{X}$ =	2.59	0.83		
						V =	8.0%	2.5%		
			Specification requirements:			$\overline{X}$ =	4.5 min.	0.3 min.		
						V =	15% max.	7.5% max.		

Table 3-7. Flexure Test Data on Panels Prepared From Prepreg Batch 4D-94

Spec. No.	Test Temp.	Prepreg Roll No.	Width (in.)	Thickness (in.)	Ult. Load (lb)		Ult. Strength (ksi)	Modulus (msi)
2888	RT	3	0.5100	0.0792	114		134	34.4
2889			0.5101	0.0806	104		118	35.1
2890			0.4999	0.0758	95		124	35.4
						Average	125	35.0
2891	RT	5	0.5002	0.0788	108		129	37.1
2892			0.5012	0.0766	110		139	36.2
2893			0.4998	0.0768	95		120	36.0
						Average	129	36.4
2894	RT	6	0.5014	0.0795	119		142	38.0
2895			0.5006	0.0804	118		138	38.5
2896			0.5002	0.0768	91		117	36.2
						Average	132	37.6
2897	RT	8	0.5006	0.0816	96		116	38.0
2898			0.5000	0.0842	93		106	36.9
2899			0.5000	0.0863	111		120	37.8
						Average	114	37.6
2900	RT	10	0.5017	0.0768	100		126	34.6
2901			0.5024	0.0775	85.5		106	33.7
2902			0.5012	0.0780	88		108	34.0
						Average	113	34.1

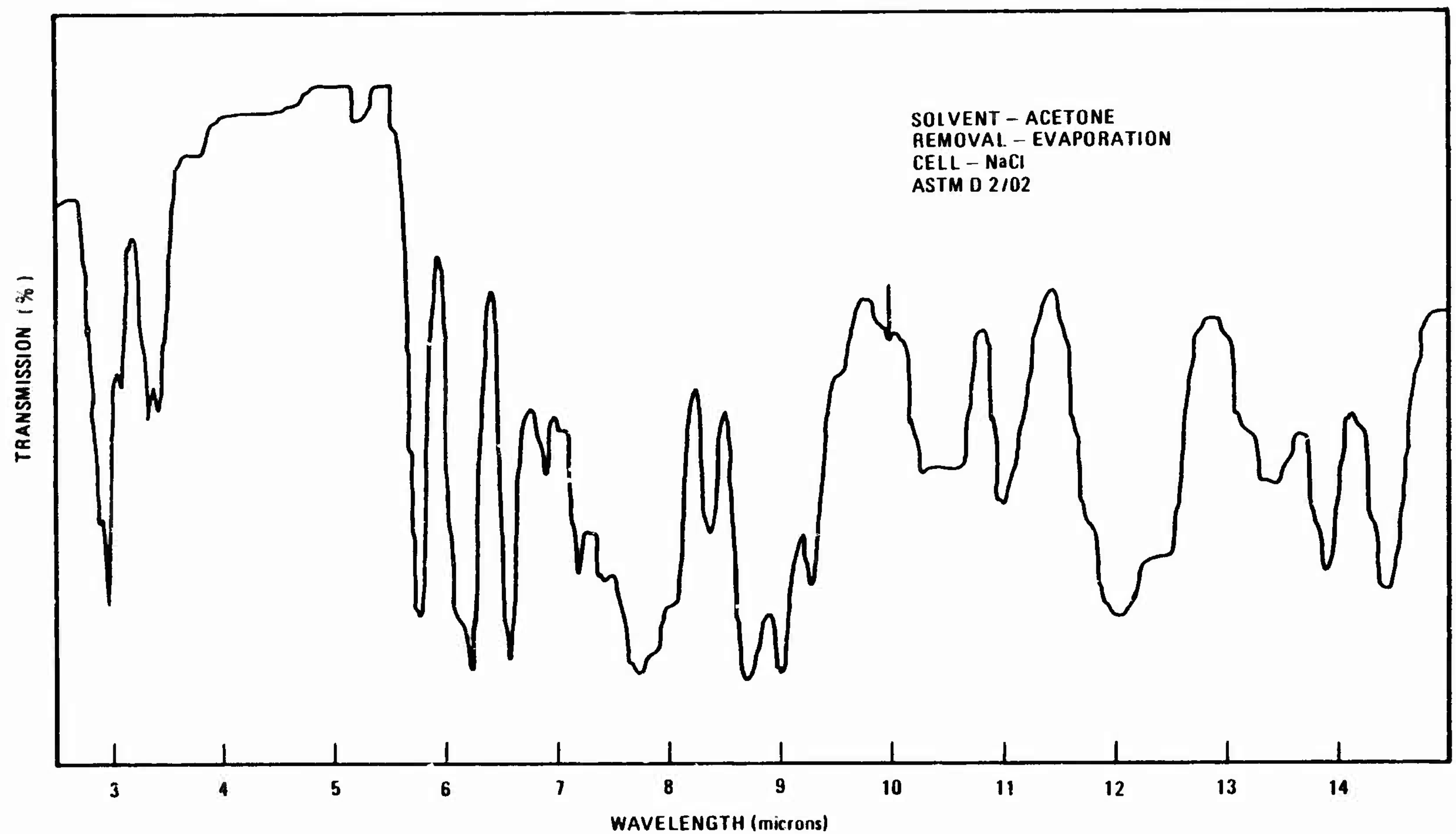


Figure 3-1. Infrared Inspection Results for Prepreg Roll Number 9, Lot 4D-94

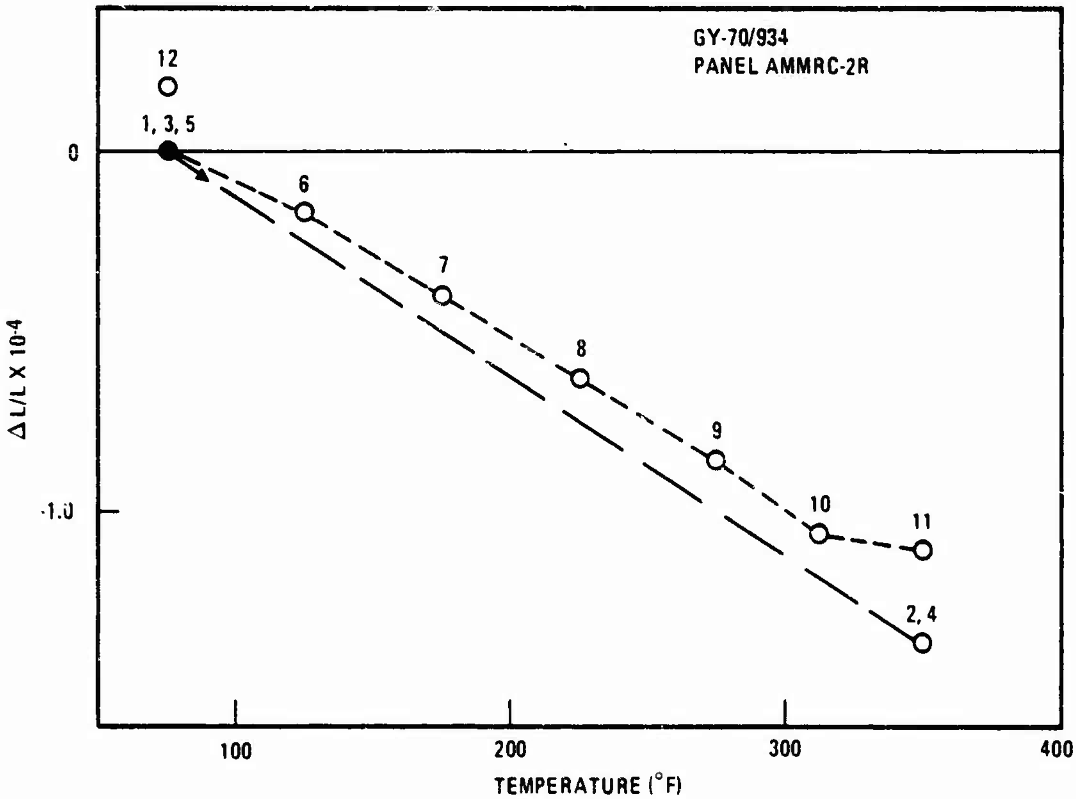


Figure 3-2. Thermal Expansion Data for 0° Specimen

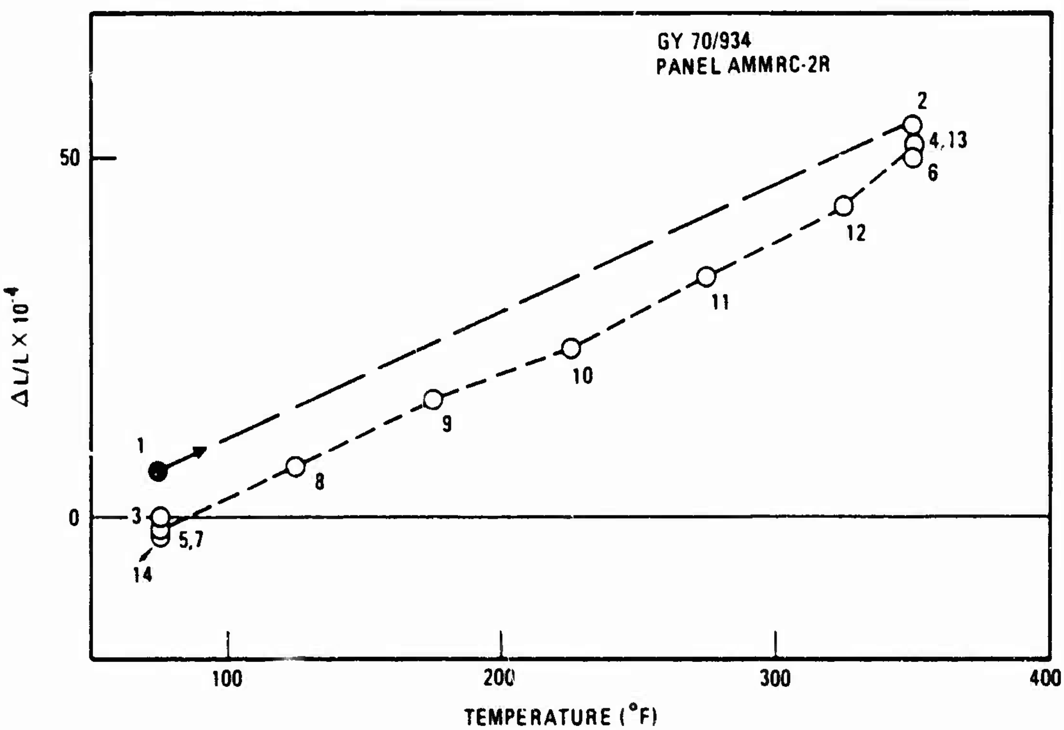


Figure 3-3. Thermal Expansion Data for 90° Specimen

SECTION 4

CONE FRUSTA FABRICATION

4.1 CONICAL FRUSTA SPECIMENS PER 48125D

Two additional batches of GY-70/934 (Fiberite's HY-E-1534) were received during the October-December 1975 period. Batch 4-E-20 consisted of 39.4 pounds and was shipped on 10-21-75. Batch 4-E-31 consisted of 167.6 pounds, with 45.5 pounds shipped on 11-6-75 and 122.1 pounds shipped on 12-1-75. Fiberite certification data is shown in Tables 4-1 to 4-3. Convair conducted receiving inspection tests on both batches of prepreg, and the results are reported in Tables 4-4 and 4-5. Both batches passed ANA747003 14-001 requirements.

Analysis by Martin-Marietta of the end rings and the cone-to-ring joints showed that thick aluminum rings were required. Convair suggested the use of Hysol's EA-9309 adhesive for the cone-to-ring joints, and ran some test specimens to evaluate the joints. The specimens were double lap joints using 0.22 inch thick GY-70/X-30 and 0.25 inch thick aluminum alloy as the adherends. The specimens were 1.0 in. wide and had a lap length of 1.5 in. giving a total bond area of 3 sq. in. per specimen. Failure loads for the five test specimens were 6130, 6775, 7600, 6750, and 6325 pounds, respectively. All failures were in the graphite/epoxy, adjacent to the grip area. Based on this testing plus additional tests at Martin-Marietta (Reference 1), the aluminum rings appeared adequate to develop ultimate loading of the graphite/epoxy in the conical frusta. The design is shown in Figure 4-1 (Drawing 48125, Rev. D).

Convair assisted Martin-Marietta in the laminate design (Reference 1), and the final layup and ply sequence was $[0_2/+45/90/-45/90/+45/0_3/-45/0_3/+45/0_2/-45/0]_s$. Convair's plan was to use female, bulk graphite molds for the fabrication of the cones. Figure 4-2 (Drawing 72C0529) shows the mold design. The molds were obtained from Electro-Nite Company, Long Beach, California, and they met all the requirements of 72C0529. A layout drawing, 72C0548, was prepared showing the gore sizes and ply layup for the first five cones, and this is shown as Figure 4-3.

The bulk graphite tools were designed with removable bulk graphite flange rings that has smaller inside diameters than the ends of the cone tool to which they bolted. Two identical tools were obtained, and wooden cradles were built to support the tools during layup. The cradles also allowed for easy rotation during layup. Figure 4-4 shows one of the tools in its cradle. A view looking into the tool is shown in Figure 4-5.

Table 4-1. Fiberite Certification Data on HY-E-1534, Batch 4-E-20

Quantity Shipped On 10-21-75	39.4 lb							
Lot No.	4-E-20							
Roll No.	2	3	4	5	6	7	8	9
Tape Size, Inches	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75
Resin Solids, %	38.6	38.1	41.2	37.8	39.9	42.7	43.6	37.2
Volatile Content, %	1.0	0.8	0.9	0.6	0.7	0.8	0.7	0.8
Laminate Flow, % @ 100 psi	16.6	21.3	20.7	20.1	21.7	22.5	23.4	18.4
Gel Time, Minutes 80C	246.0	250.0	239.0	227.8	231.5	233.5	240.1	210.0
121C	112.1	118.5	120.0	123.2	119.5	118.0	121.0	105.0
177C	5.8	6.7	7.1	7.0	7.4	6.8	7.0	7.0
Resin Type	Type A (Fiber sizing is compatible with the resin system used)							
Tack	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Drape	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Fiber Volume, %	67.36							
Resin Content, %	24.6 (Cured Panel)	Fiber Properties Attached						
Flexural Strength (psi) *	R.T. = 123,489							
*	350F = 127,795							
Flexural Modulus (10^6 psi) *	R.T. = 38.06	*Values are normalized to 63% fiber volume						
*	350F = 37.61							
Void Content	-0.323							
Horizontal Beam Shear (psi)	R.T. = 9,565 350F = 8,164	The prepreg tow, when laminated into unidirectional specimens, shall possess the properties required in Table IV of subject specification.						
Date of manufacture	10-17-75	The raw material and process used in manufacturing of the finished product have not been changed.						
Shelf Life	6 mos @ 0F max.							

Fiber Data

		Lot No. ST-4-125			Lot No. ST/3-126
Bobbin No.	=	24	32, 33, 34, 35, 36	=	13 & 14
Tensile Strength, (ksi)	=	292	336	=	273
Tensile Modulus, (msi)	=	74	80	=	76
Density, (gm/cc)	=	1.98	1.99	=	1.98

Table 4-2. Fiberite Certification Data on HY-E-1534, Batch 4-E-31 (first shipment)

Quantity Shipped on 11/6/75	45.5 lb							
Lot No.	4-E-31							
Roll No.	2	3	4	5	6	7	8	9
Tape Size, Inches	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75
Resin Solids, %	38.3	39.2	40.1	38.0	37.3	38.4	37.2	40.0
Volatile Content, %	0.7	0.7	0.8	0.8	1.0	0.9	0.5	0.8
Laminate Flow, % @ 100 psi	16.0	22.4	22.1	19.6	19.3	21.0	18.4	19.9
Gel Time, Minutes 80C	321	333.7	315	325	318.2	324.1	321.2	324.6
121C	98.6	100.4	102	107.6	110.4	107.7	110.4	109.3
177C	7.1	8.3	8.3	8.7	8.4	8.6	8.9	7.4
Tack	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Drape	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass

Resin Type	Type A (Fiber sizing is compatible with the resin system used)	
Fiber Volume, %	67.1	
Resin Content, %	24.1 (Cured Panel)	Fiber Properties Per Attached
Flexural Strength (psi) *	R.T. = 131,165	
*	350F = 107,441	*Values are normalized to 63% fiber volume.
Flexural Modulus (10^6 psi) *	R.T. = 41.56	
*	350F = 38.65	
Void Content	-0.783	The prepreg tow, when laminated into unidirectional specimens, shall possess the properties required in Table IV of subject specification.
Horizontal Beam Shear (psi)	R.T. = 8,168 350F = 7,169	
Date of manufacture	11/6/75	The raw material and process used in manufacturing the finished product have not been changed.
Shelf Life	6 mos. @ 0F max.	

<u>Fiber Data</u>

<u>ST/3-122</u>

Bobbin No.	=	'9
Tensile Strength, (ksi)	=	267
Tensile Modulus, (msi)	=	75
Density, (gm/cc)	=	1.97

Table 4-2. Fiberite Certification Data on HY-E-1534, Batch 4-E-31 (first shipment), Contd

Fiber Data, Contd

ST/3-124

Bobbin No.	=	14	31	28	
Tensile Strength, (ksi)	=	260	236	275	
Tensile Modulus, (msi)	=	70	71	75	
Density, (gm/cc)	=	1.95	1.94	1.96	

ST/3-126

Bobbin No.	=	16
Tensile Strength, (ksi)	=	273
Tensile Modulus, (msi)	=	76
Density, (gm/cc)	=	1.98

ST/4-123

Bobbin No.	=	4
Tensile Strength, (ksi)	=	270
Tensile Modulus, (msi)	=	74
Density, (gm/cc)	=	1.97

ST/4-128

Bobbin No.	=	17	30,31	38,40	49
Tensile Strength, (ksi)	=	285	278	281	270
Tensile Modulus, (msi)	=	71	75	74	74
Density, (gm/cc)	=	1.96	1.96	1.96	1.95

Table 4-3. Fiberite Certification Data on HY-E-1534, Batch 4-E-31 (second shipment)

Quantity Shipped on 12/1/75	122.1 lb								
Lot No.	4-E-31								
Roll No.	16	17	18	19	20	21	22	23	24
Tape Size, Inches	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75
Resin Solids, %	38.7	40.6	37.0	39.4	38.4	41.8	42.3	38.4	37.0
Volatile Content, %	0.9	0.8	0.9	0.9	0.6	0.6	0.7	0.7	0.8
Laminate Flow, % @ 50 psi	17.9	20.7	15.0	19.4	21.5	22.5	23.6	17.3	18.0
Gel Time, Minutes 80C	307.2	289.0	296.0	306.0	290	312.0	315.0	310.0	306.0
121C	110.0	100.2	115.8	114.6	117.4	116.8	116.9	112.2	115.5
177C	7.7	9.5	9.8	9.0	10.4	10.7	10.0	10.2	10.5
Tack	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Drape	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Resin Type	Type A (Fiber sizing is compatible with the resin system used)								
Fiber Volume, %	67.1								
Resin Content, %	24.1 (Cured Panel) Fiber properties per attached								
Flexural Strength (psi) *	R.T. = 131,165								
*	350F = 107,441 *Values are normalized to 63% fiber volume.								
Flexural Modulus (10^6 psi) *	R.T. = 41.56								
*	350F = 38.65								
Void Content	-0.783 The prepreg tow, when laminated into unidirectional specimens, shall possess the properties required in Table IV of subject specification.								
Horizontal Beam Shear (psi)	R.T. = 8,168								
	350F = 7,169								
Date of manufacture:	11/28/75								
Shelf Life	6 mos. @ 0F max.								

Quantity Shipped on 12/1/75								
Lot No.	4-E-31							
Roll No.	25	26	27	28	29	30	31	32
Tape Size, Inches	2.75	2.75	2.75	2.75	2.75	2.75	2.75	2.75
Resin Solids, %	42.4	43.0	43.0	37.4	38.6	37.5	39.1	37.3
Volatile Content, %	0.9	0.7	0.7	0.6	0.7	0.5	0.5	0.5
Laminate Flow, % @ 50 psi	23.3	19.4	16.4	18.8	17.9	15.0	15.1	17.1
Gel Time, Minutes 80C	300.0	317.0	287.0	287.0	289.4	286.2	281.0	280.0
121C	116.3	118.0	98.6	114.6	109.1	107.3	110.0	102.0
177C	11.4	11.0	7.8	7.8	8.0	7.9	7.5	7.3
Tack	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass
Drape	Pass	Pass	Pass	Pass	Pass	Pass	Pass	Pass

Table 4-3. Fiberite Certification Data on HY-E-1534, Batch 4-E-31 (second shipment), (Contd)

Quantity Shipped on 12/1/75							
Lot No.		4-E-31					
Roll No.		33	34	35	36	37	38
Tape Size, Inches		2.75	2.75	2.75	2.75	2.75	2.75
Resin Solids, %		40.2	37.6	41.1	38.2	42.5	40.4
Volatile Content, %		0.4	0.6	0.5	0.7	0.8	0.5
Laminate Flow, % @	50 psi	15.2	15.0	19.9	15.4	22.0	22.5
Gel Time, Minutes	80C	290.6	285.5	281.0	291.4	293.5	298.8
	121C	105.7	103.6	101.0	97.2	100.6	98.0
	177C	7.6	7.4	8.6	8.5	8.3	8.8
Tack		Pass	Pass	Pass	Pass	Pass	Pass
Drape		Pass	Pass	Pass	Pass	Pass	Pass

Fiber Data

ST/2-078

Bobbin No.	=	60
Tensile Strength, (ksi)	=	260
Tensile Modulus, (msi)	=	71
Density, (gr/cc)	=	1.93

ST/2-080

Bobbin No.	=	14
Tensile Strength, (ksi)	=	257
Tensile Modulus, (msi)	=	71
Density, (gr/cc)	=	1.93

ST/3-124

Bobbin No.	=	27	33
Tensile Strength, (ksi)	=	275	328
Tensile Modulus, (msi)	=	75	78
Density, (gr/cc)	=	1.96	1.96

ST/4-125

Bobbin No.	=	18	20	21	23	25	33	34	35
Tensile Strength, (ksi)	=	292	292	292	292	292	336	336	336
Tensile Modulus, (msi)	=	74	74	74	74	74	80	80	80
Density, (gr/cc)	=	1.98	1.98	1.98	1.98	1.98	1.99	1.99	1.99

Table 4-3. Fiberite Certification Data on HY-E-1534, Batch 4-E-31 (second shipment), (Contd)

ST/3-126

Bobbin No.	=	12
Tensile Strength, (ksi)	=	284
Tensile Modulus, (msi)	=	73
Density, (gr/cc)	=	1.97

ST/3-127

Bobbin No.	=	2	3
Tensile Strength, (ksi)	=	261	261
Tensile Modulus, (msi)	=	74	74
Density, (gr/cc)	=	1.96	1.96

ST/4-128

Bobbin No.	=	35
Tensile Strength, (ksi)	=	281
Tensile Modulus, (msi)	=	74
Density, (gr/cc)	=	1.96

ST/4-132

Bobbin No.	=	2	5 & 6	7	9, 11 & 12 & 13
Tensile Strength, (ksi)	=	317	251	278	253
Tensile Modulus, (msi)	=	74	72	72	73
Density, (gr/cc)	=	1.93	1.94	1.96	1.97

Table 4-4. Convair Test Results on Prepreg Batch 4-E-20, Roll 5

	Volatiles (%)	Resin Flow (%)	Resin Solids (%)	Drape	Tack	Gel Time at 350F	Gel Time at 280F
	0.45	17.9	38.3	Pass	Pass	6 min. 35 sec.	38 min.
	0.52	14.6	37.5	Pass	Pass	7 min. 10 sec.	
	0.58	17.4	37.9	Pass	Pass		
Average	0.52	16.6	37.9	Pass	Pass		
Spec. Req.	2.0 max.	20 ± 5	40 ± 3	Pass	Pass	To be reported per specification.	

Table 4-5. Convair Test Results on Prepreg Batch 4-E-31

	Volatiles (%)	Resin Flow (%)	Resin Solids (%)	Drape	Tack	Gel Time at 350F	Gel Time at 250F
Shipment 1,	0.7	18.9	37.9	Pass	Pass		
Roll 6	0.5	15.8	37.6	Pass	Pass		
	0.6	18.3	37.6	Pass	Pass		
	0.6	14.3	38.6	Pass	Pass		
	0.6	15.3	38.9	Pass	Pass		
Average	0.6	16.5	38.1	Pass	Pass		
Spec. Req.	2.0 max	20 ± 5	40 ± 3	Pass	Pass	To be reported	
Shipment 2,	0.66	23.4	42.1	Pass	Pass	7 min. 20 sec.	82 min.
Roll 22	0.81	26.7	43.7	Pass	Pass	7 min. 0 sec.	84 min.
	0.63	14.8	42.5	Pass	Pass	7 min. 30 sec.	82 min.
	0.55	26.0	42.9	Pass	Pass		
	0.68	24.3	42.8	Pass	Pass		
Average	0.67	23.0	42.8	Pass	Pass	7 min. 17 sec.	83 min.
Spec. Req.	2.0 max.	20 ± 5	40 ± 3	Pass	Pass	To be reported	

NOTES:

1. GY70/FIBERITE 934 PLY LAMINA LAYUP: $[0_2/45/90/-45/90/45/0_2/-45/0_3/45/0_2/-45/0]_S$
2. ALUMINUM RINGS SHALL BE FLUSH WITH ENDS OF SHELL
3. CLEAN ALUM RINGS PER PROCEDURE IN MIL-A-9067O, PARA 6.1.1, OR EQUIV AND BOND WITHIN 8 HOURS. SOLVENT WIPE GY70 SHELL BONDING SURFACES WITH PETROLEUM ETHER OR EQUIV, DRY, HAND SAND LIGHTLY, AND REMOVE DUST WITH DRY NITROGEN. BOND ALUM RINGS TO GY70 SHELL WITH EA9309 (HYSOL DIV, THE DEXTER CORP) PER VENDOR'S RECOMMENDED MIX RATIO. MAINTAIN BOND LINE THICKNESS OF 0.004 IN. TO 0.125 IN. CURE FOR 72 HRS AT 75°F ± 5°F OR FOR 6 HRS AT 75°F ± 5°F PLUS 16 HRS AT 120°F ± 10°F
4. ORIGINAL LENGTH OF SHELL FABRICATED IN MANDREL IS 9.300 IN. THIS LENGTH SHALL BE REDUCED BY 0.100 IN. AT EACH END TO REMOVE IRREGULARITIES
5. GY70 SHELL AND ALUMINUM RING BONDING SURFACE DIAMETERS SHALL BE CONCENTRIC WITHIN 0.02 IN.

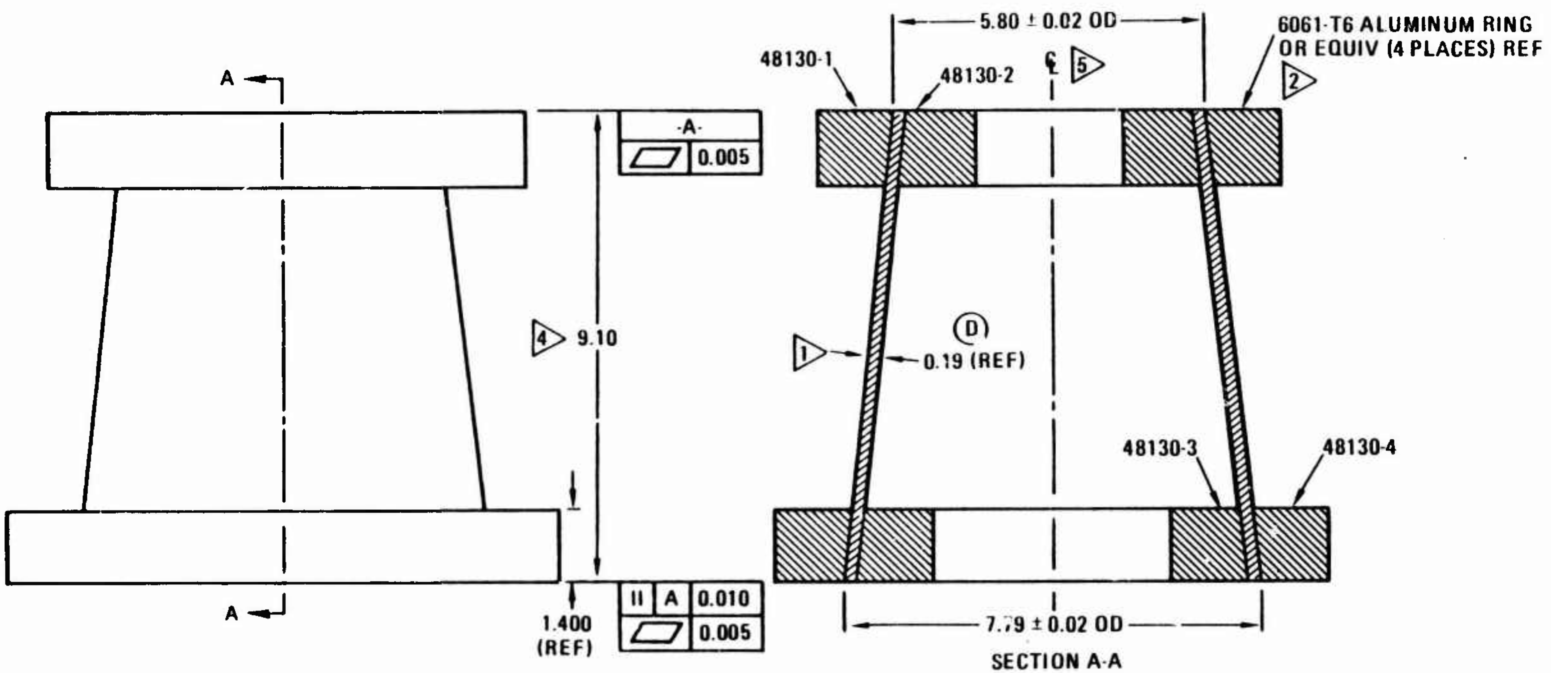
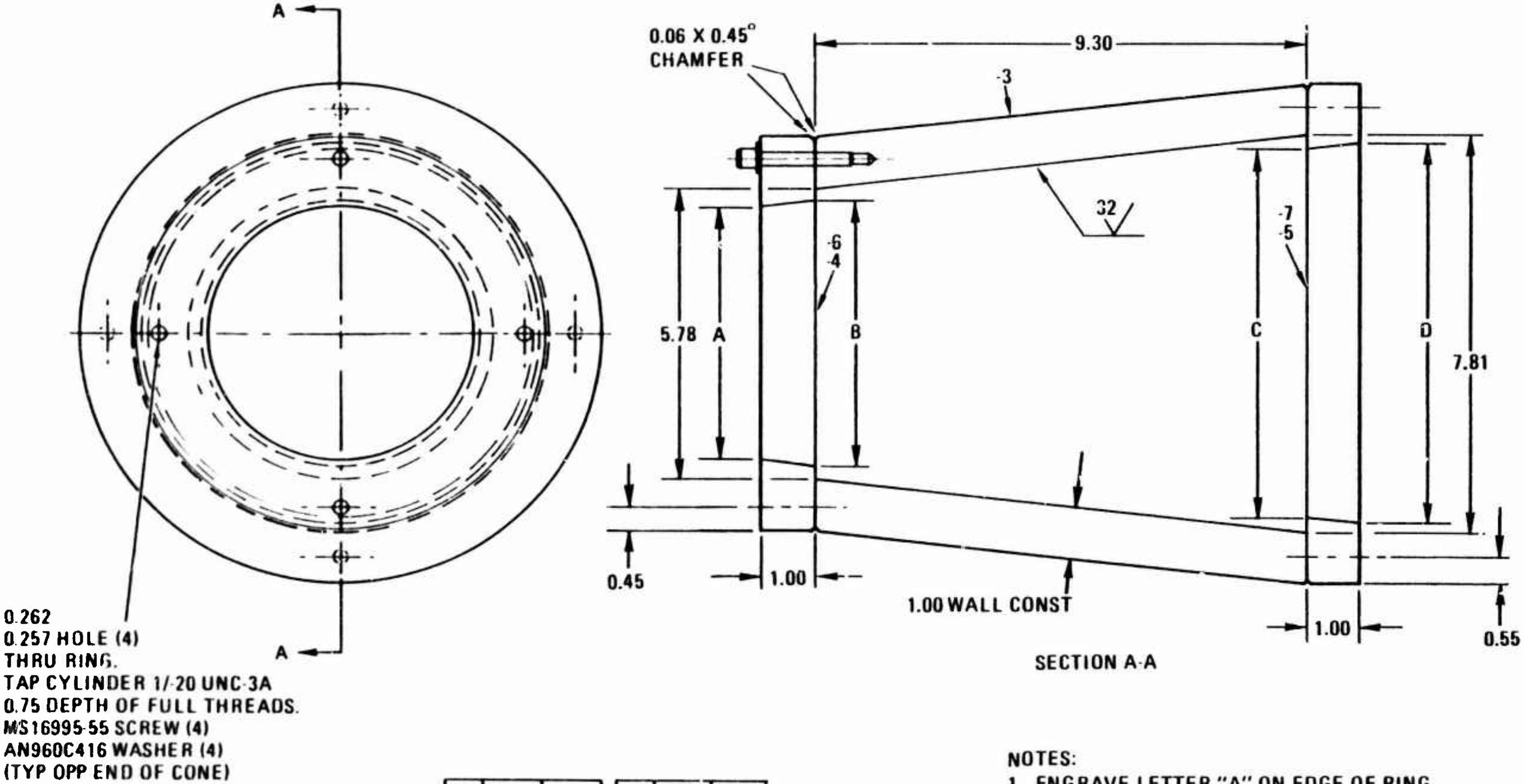


Figure 4-1. Drawing 48125 (Revision D), GY70/Epoxy Conical Shell



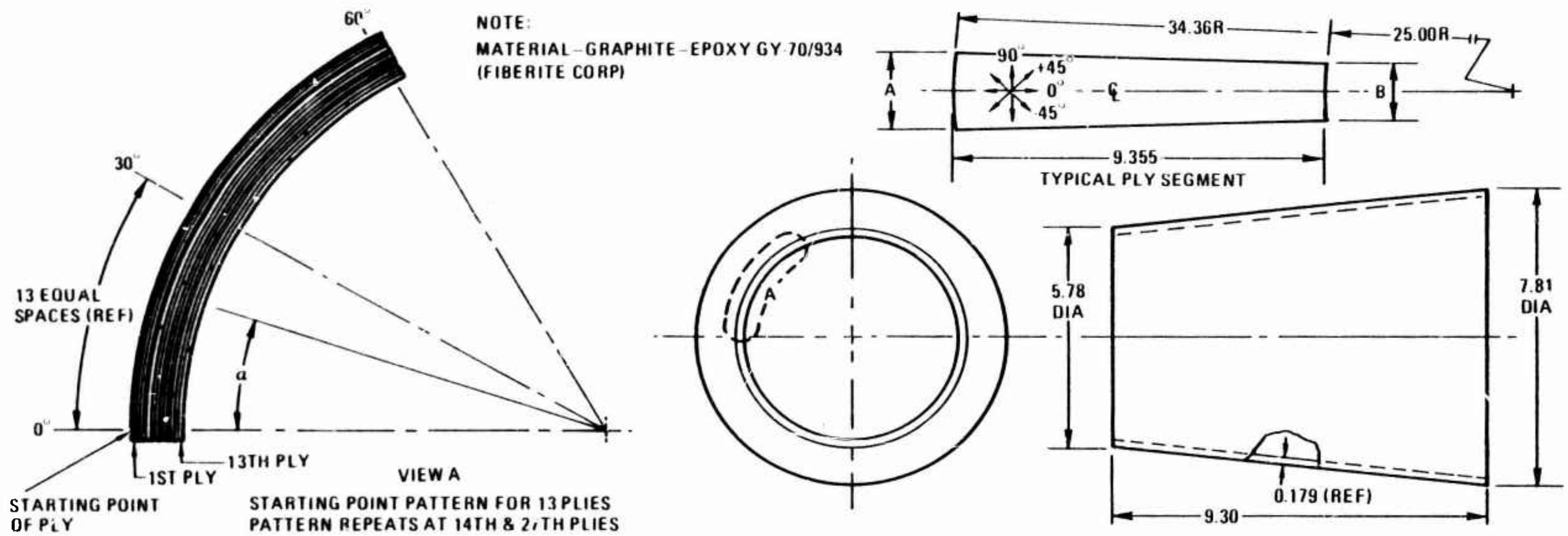
	A	B
-4	5.06	5.28
-6	4.86	5.08

	A	B
-5	7.31	7.53
-7	7.11	7.33

NOTES:

1. ENGRAVE LETTER "A" ON EDGE OF RING AND AT ADJACENT POINT ON END OF CONE (SMALL END). AT OPP END ENGRAVE LETTER "B" IN SAME MANNER (LARGE END). 0.38 HIGH LETTERS
2. -4 & -5 RINGS SHALL BE INTERCHANGEABLE WITH -6 & -7 RINGS RESPECTIVELY

Figure 4-2. Mold Design (Drawing 72C0529)



	PLY NO.	THEORETICAL SEGMENT DIM. A	THEORETICAL SEGMENT DIM. B	ORIENTATION OF PLY	a	SEGMT WRAP ANGLE	PLY NO.	THEORETICAL SEGMENT DIM. A	THEORETICAL SEGMENT DIM. B	ORIENTATION OF PLY	a	SEGMT WRAP ANGLE	
	1	2.040	1.510	0°	0° 0'	30°	20	1.985	1.455	0°	20°45'	30°	
	2	2.035	1.505	0°	18°30'	30°	Δ 21	5.942	4.348	-45°	9°15'	90°	
	3	6.090	4.495	+45°	7° 0'	90°	22	1.975	1.445	0°	27°45'	30°	
	4	6.075	4.480	90°	25°30'	90°	23	1.970	1.440	0°	16°15'	30°	
	5	6.060	4.465	-45°	13°45'	90°	Δ 24	5.897	4.303	+45°	4°30'	90°	
	6	6.045	4.450	90°	2°15'	90°	25	1.960	1.430	0°	23° 0'	30°	
	7	6.030	4.435	+45°	20°45'	90°	26	1.955	1.425	0°	11°30'	30°	
	8	2.005	1.475	0°	9°15'	30°	27	1.950	1.420	0°	0° 0'	30°	
	9	2.000	1.470	0°	27°45'	30°	Δ 28	5.836	4.242	-45°	18°30'	90°	
PRE PLY	10	1.995	1.465	0°	16°15'	30°	29	1.940	1.410	0°	7° 0'	30°	PRE PLY
	Δ11	5.970	4.375	-45°	4°30'	90°	30	1.935	1.405	0°	25°30'	30°	
	12	1.985	1.455	0°	23° 0'	30°	31	1.930	1.400	0°	13°45'	30°	
	13	1.980	1.450	0°	11°30'	30°	32	5.778	4.185	+45°	2°15'	90°	
	14	1.975	1.445	0°	0° 0'	30°	33	5.764	4.170	90°	20°45'	90°	
	Δ15	5.911	4.317	+45°	18°30'	90°	34	5.749	4.155	-45°	9°15'	90°	
	16	1.965	1.435	0°	7° 0'	30°	35	5.735	4.140	30°	27°45'	90°	
	17	1.960	1.430	0°	25°30'	30°	36	5.720	4.125	+45°	16°15'	90°	
	Δ18	5.866	4.272	-45°	13°45'	90°	37	1.900	1.370	0°	4°30'	30°	
PRE BLEED TO 0.103 THICKNESS	19	1.950	[illegible]	0°	2°15'	30°	38	1.895	1.365	0°	23° 0'	30°	FINAL CURE

Δ ADD 0.25 TO A&B DIMS TO PROVIDE 0.25 OVERLAP OF SEGMENTS

Figure 4-3. Layout Drawing for First Five Cones (Drawing 72C0548)

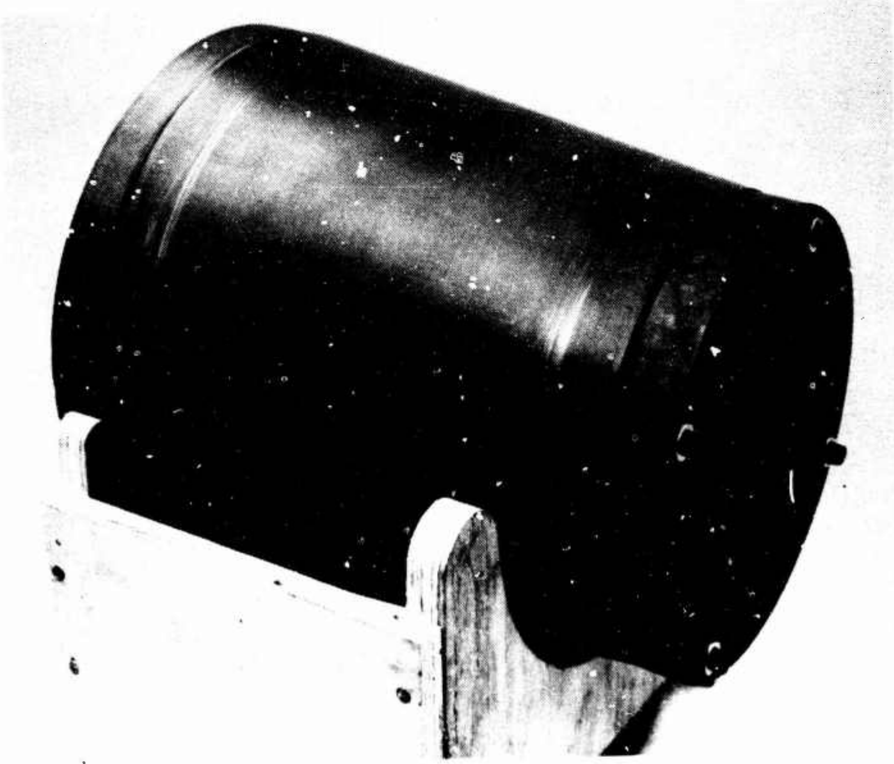


Figure 4-4. Bulk Graphite Tool in Cradle

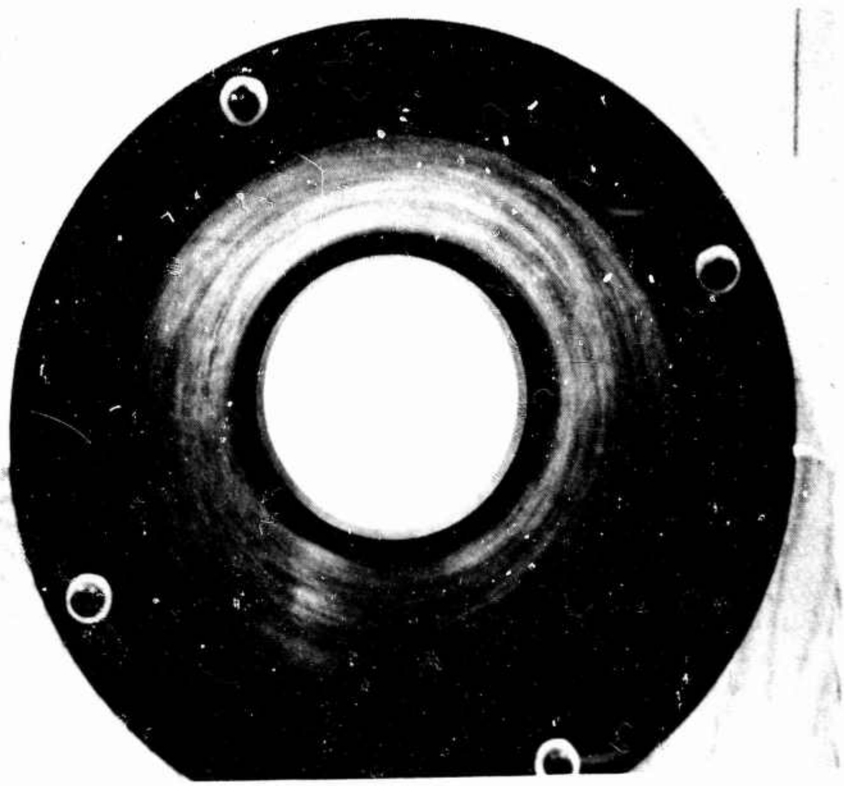


Figure 4-5. Graphite Tool Interior

Large unidirectional sheets of GY-70/934 were prepared by layup of parallel and butted plies of the 2.75 in. unidirectional prepreg tape. The sheets were laid between sheets of perforated Teflon coated glass cloth and placed under a vacuum bag at a minimum pressure of 29 in. of mercury and held at room temperature for a minimum of 15 minutes. After debagging, gores were cut from the large sheet using predetermined templates as shown in Figure 4-6. Gores were placed into the tool by first removing one layer of the separator film and then laying the gore in at a predetermined location per Figure 4-3. Protractors were designed to fit on both front and back of the tool when the flanges were removed. This allowed for accurate placement of the gores as shown in Figure 4-7.

The tools were designed so that they would produce an 8.5 in. cone frustum after trimming approximately 0.4 in. from each end. This trimming would remove the more prominent local surface discontinuities of the cones that generally occur near edge dams. The final ring design by Martin Marietta necessitated a frustum length of 9.1 in. This allowed a trim of only 0.1 in. at each end using the already existent tools.

A detailed step-by-step procedure for cone fabrication is given below:

1. Lay up sufficient large sheets of unidirectional GY-70/934 to prepare all gores needed for layup of one cone. Note batch and roll numbers of all prepreg used in layup.

2. Remove flanges from bulk graphite tool. Apply FreKote 33 to tool and bake for one hour at 300F. Attach protractors to front and back ends of tool.

3. Lay up plies 1 to 10 per Figure 4-3. Remove protractors. Trim material to edge of cone tool, and replace tool flanges.

4. Apply one ply of porous Teflon glass cloth separator over layup and then one or two plies of style 7581 glass cloth bleeder. Apply a thin silicone rubber sheet overpress. Envelope bag with VacPak or equivalent film.

5. Apply a minimum vacuum of 24 inches of mercury and preply at room temperature (RT) for a minimum of 30 minutes.

6. Debag and remove the ring flanges. Install protractors.

7. Lay up plies 11 to 19 per Figure 4-3.

8. Remove protractors and install end rings. Apply bleeder system consisting of one ply of porous Teflon coated glass separator film and six plies of style 7581 glass cloth. Apply silicone rubber overpress followed by the two plies of style 1534 glass cloth to serve as a vent. Place two thermocouples in trim areas of layup. Envelope bag with VacPak or equivalent film.

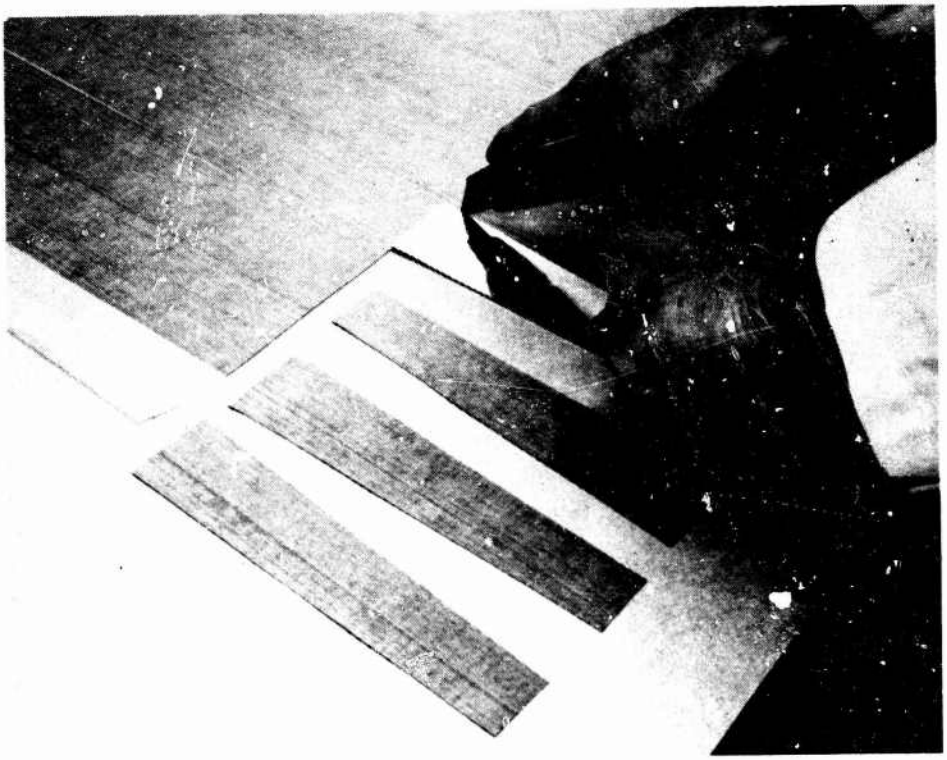


Figure 4-6. Cutting Gores

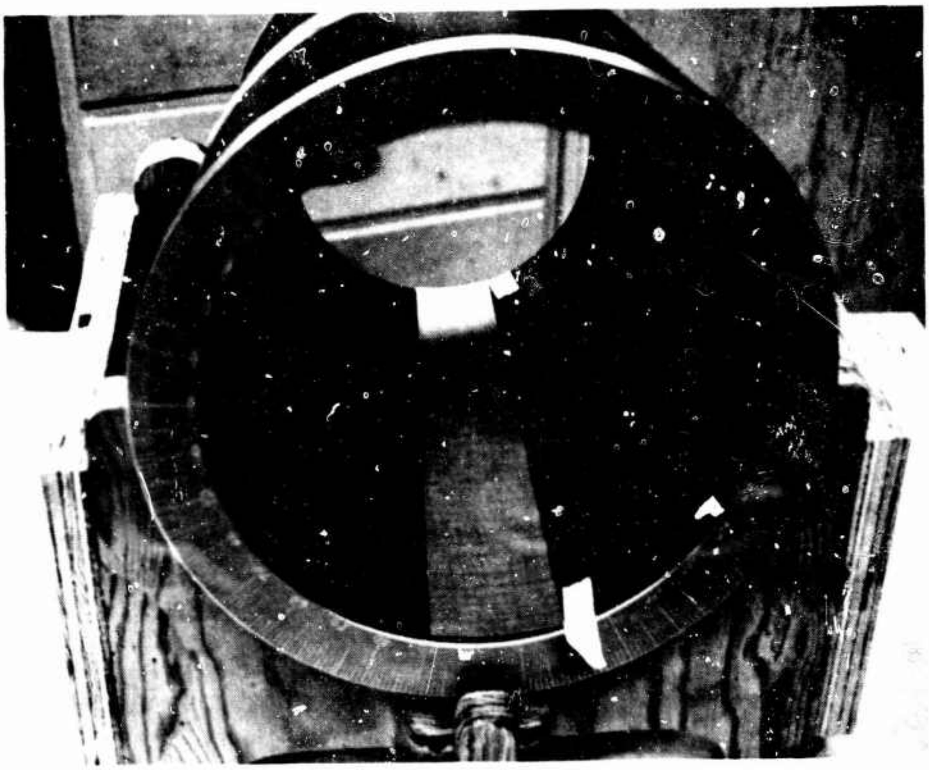


Figure 4-7. Protractor Used for Placement of Gores

9. Precompact as follows: Apply a minimum vacuum of 24 inches of mercury on bag at RT. Heat in autoclave at 2 to 5F/minute to 160±5F. Apply 50±5 psig autoclave pressure and hold for 15 to 20 minutes. Cool under vacuum and pressure to below 100F at a maximum rate of 5F/minute.

10. Vent and debag. Remove ring flanges and install protractors.

11. Lay up plies 20 to 29 per Figure 4-3.

12. Prepare for preplying per step 4.

13. Preply per step 5.

14. Debag per step 6.

15. Lay up plies 30 to 38 per Figure 4-3.

16. Remove protractors and install end rings. Apply bleeder system consisting of one ply of porous Teflon coated glass separator film, one ply of style 120 glass cloth, and two plies of style 7581 glass fabric. Apply silicone rubber overpress followed by two plies of style 1534 glass cloth to serve as a vent. Place two thermocouples in trim area of layup. Envelope bag with VacPak or equivalent film.

17. Cure as follows: Apply a minimum vacuum of 24 inches of mercury on bag at RT. and hold for a minimum of 30 minutes before heating. Heat part in autoclave at a rate of 2 to 4F/minute to 250±10F. Hold at 250±10F for 45±5 minutes, and then apply 100±5 psig autoclave pressure in less than five minutes. Hold an additional 45±5 minutes at temperature and pressure. Raise temperature to 350±10F at 2 to 4F/minute. Hold at temperature and pressure for a minimum of two hours. Cool at a rate not to exceed 10F/minute (pressure and vacuum optional).

18. Debag and remove part from tool.

19. Trim 0.1 inch from each end of cone frustum to conform with Drawing 48125.

20. Mask outside of cone frustum in areas not to be bonded. Sand lightly inside and outside of cone at both top and bottom where rings are to be bonded. Use Scotch-brite pads for sanding.

21. Solvent clean bond areas with methylethylketone or trichloroethane. Dry for a minimum of 30 minutes prior to bonding.

22. Rings machined per Drawing 48130 (Figure 4-8) shall be etched and bonded per Drawing 48125. The adhesive to be used shall be Hysol's EA9309. A minimum cure of 24 hours at RT shall be allowed between operations. The sequence of ring bonding shall be 48130-2, 48130-3, 48130-4, and 48130-1. If necessary fill any local bond voids with EA9309.

23. Inspect dimensions of finished cone per Drawing 48125.

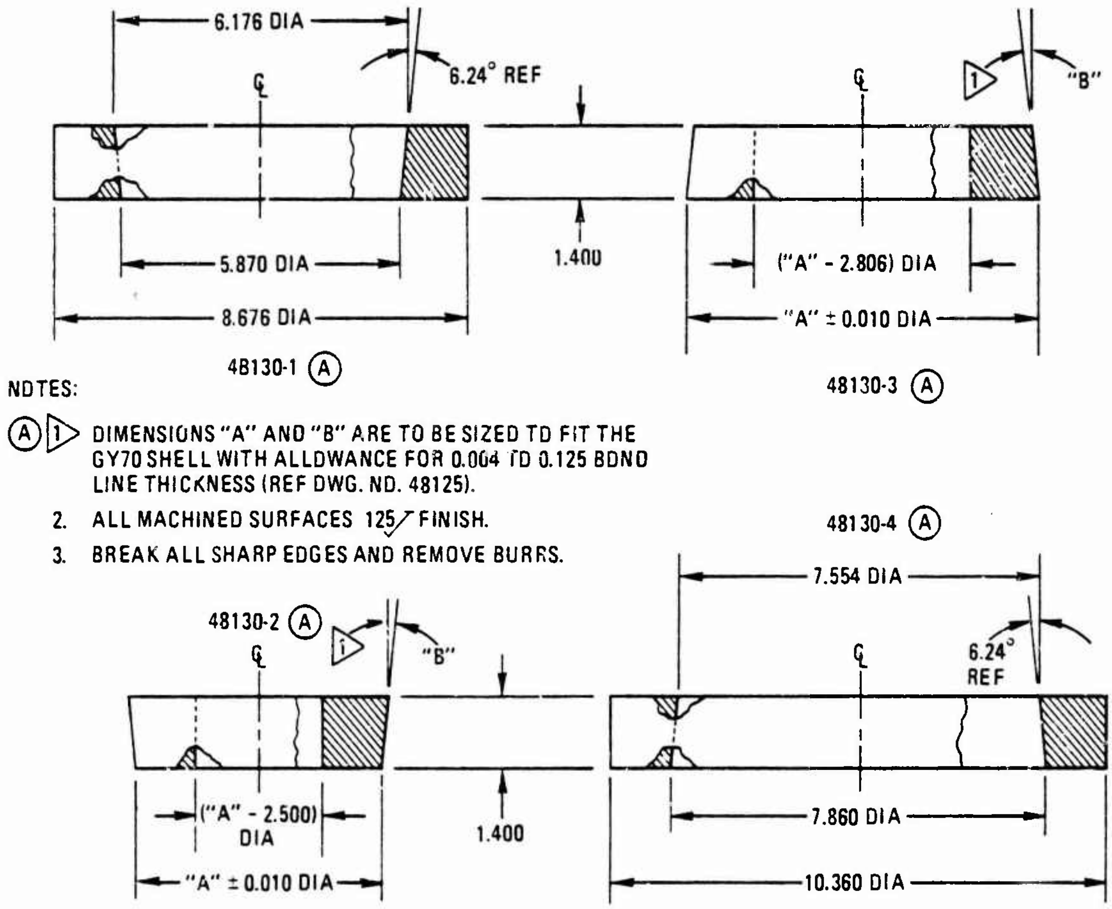


Figure 4-8. Drawing 48130, Support Rings

Removal of the bleeder after cure is one of the more difficult tasks since it is completely filled with cured resin, tough, and difficult to cut without damaging the cone frustum. It was initially felt that the cones might be difficult to remove from the bulk graphite tools. The first one was removed in a press. The tool containing the part rested on a wood form, which had a ledge to support the tool and had a center hole through which the part could drop. A block having the outside diameter of the part was placed on the part and pressed as shown in Figure 4-9. The part came out so easily that the rest of the parts were easily removed by hand (see Figure 4-10).

Figure 4-11 shows a trimmed cone frustum and the four aluminum rings. Difficulty was encountered in meeting the concentricity requirements between part and rings as specified on Drawing 48125. Because of the fluidity of the EA9309 adhesive, some adhesive flash occurred on the upper and lower ring surfaces. In most cases a cleanup cut was required to obtain the flatness and parallelism requirements of Drawing 48125. Figure 4-12 shows a typical cone with bonded rings as shipped to Martin Marietta, Orlando, Florida. The cones flanges were drilled at Martin as shown in Figure 4-13 to allow bolting of the cones into the test fixtures.

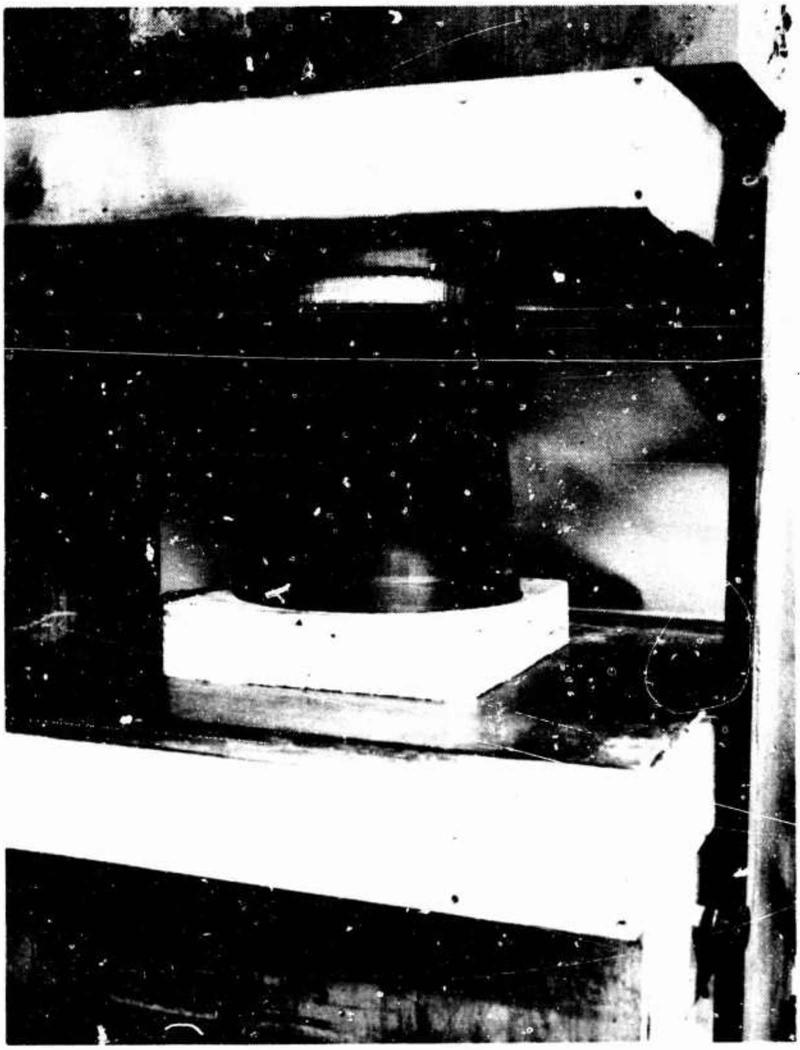


Figure 4-9. Removing Cone Frustum from Bulk Graphite Tool by Press

Table 4-6 is a summary of the dimensions on the first five cones. Of the first five, only cones 3 and 5 were initially out on flatness on the large end (0.007 and 0.006 in., respectively). These cones were faced, and the final flatness readings were 0.001 and 0.002 in., respectively. The facing produced improved parallelism as well as improved flatness. Cone 4 failed to meet the concentricity requirement of Drawing 48125D. Instead of 0.02 in. maximum, the small end had its rings concentric to 0.06 in. in the worst case. Therefore, a deviation was obtained from AMMRC, and cone 4 was used for a compression test rather than a combined loading test. Wall thickness was not a definite requirement for the cone frusta, with the Drawing 48125D specifying a nominal 0.19 in. The first three cones produced were measured at four locations at top, center, and bottom, and the thicknesses varied from 0.180 to 0.194 in.

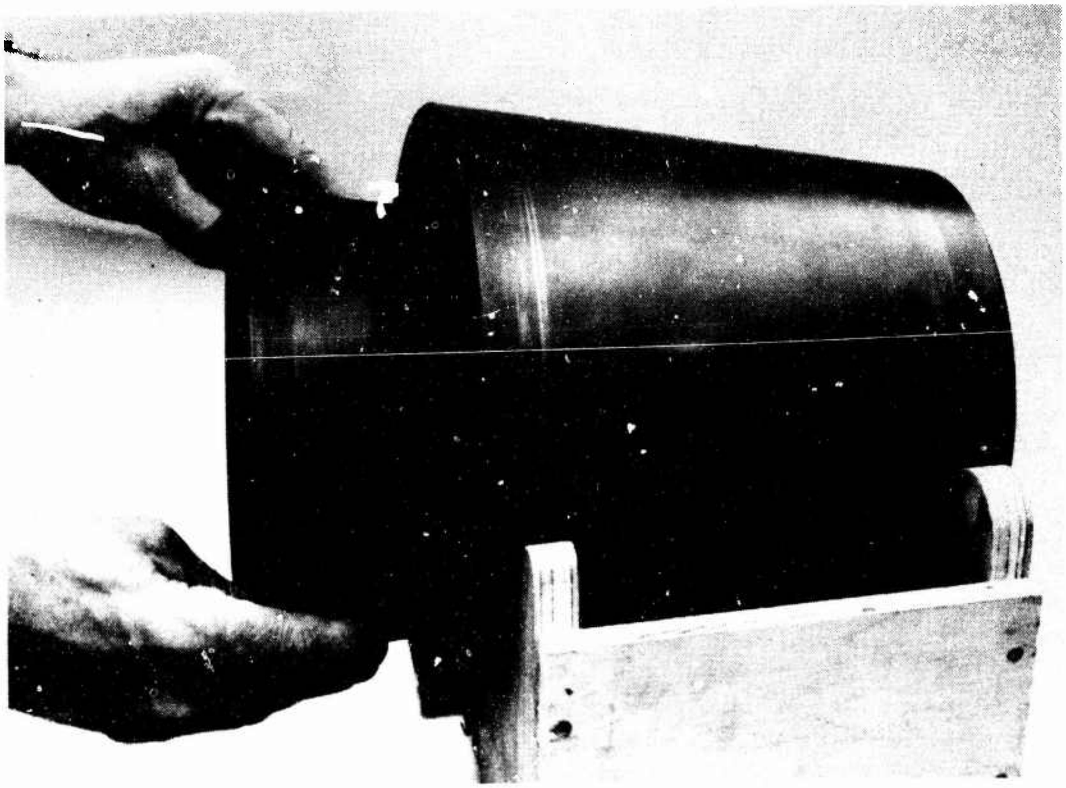


Figure 4-10. Removing Cone Frustum from Bulk Graphite Tool by Hand

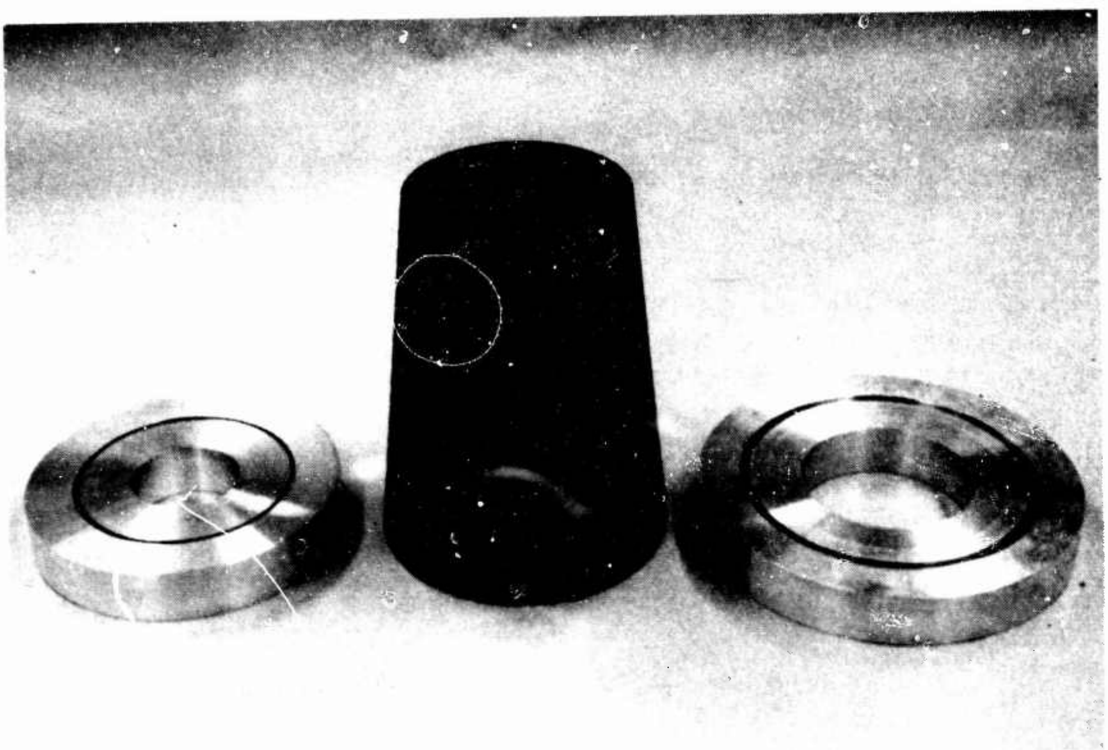


Figure 4-11. Trimmed Cone Frustum and Four Aluminum Rings

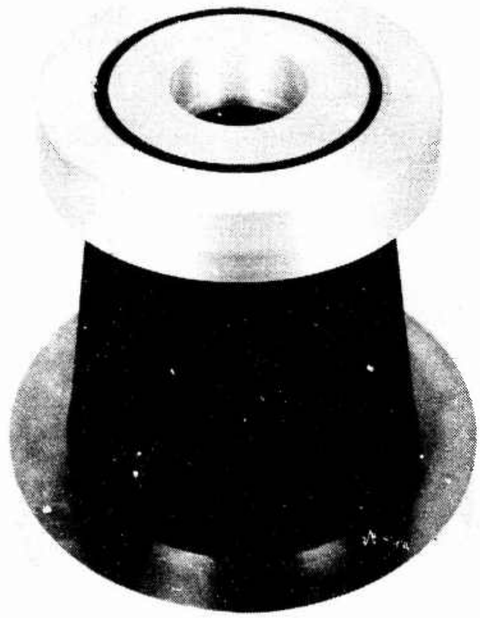


Figure 4-12. Trimmed Cone Frustum with Bonded Rings

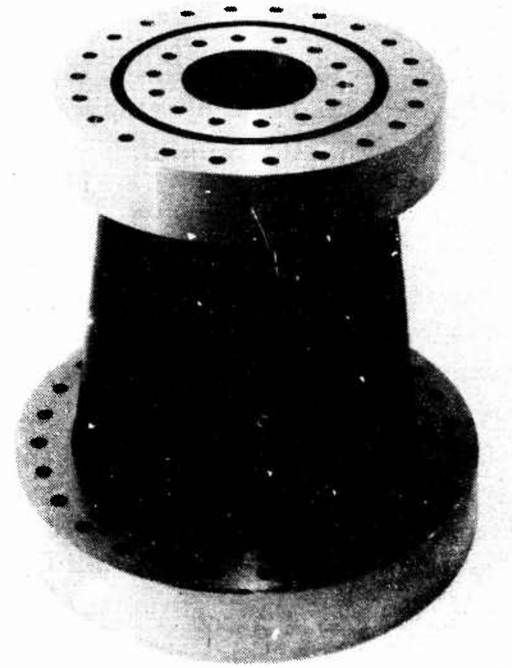


Figure 4-13. Frustum with Flanges Drilled

They were extremely uniform except for some local high spots within 0.5 in. of each end. The end nonuniformity had been anticipated. It is attributed to bleeder bunching during precompaction and cure. The large allowable variation in bondline thickness accommodated these local wall thickness variations.

The first five GY-70/934 conical shells were tested by Martin Marietta Corporation at Orlando, Florida under various combination of loads, and the results are summarized in Table 4-7. The results were outstanding and compared well with predictions. Therefore, as a result of an AMMRC/Martin Marietta/General Dynamics meeting it was decided that it would be more beneficial to prepare five more conical shells of the original layup than to attempt to evaluate a minor modification of the original layup. It was also decided to reuse the original aluminum rings as a way of reducing costs. A drill fixture, designed and fabricated at Martin Marietta for drilling bolt hole patterns in the aluminum rings, was shipped to General Dynamics as an aid for building a bond fixture. This was required since bonding of the predrilled rings had to be accomplished in such a manner that the subsequent conical shells would fit in existing test fixtures. This required holding a definite relationship between inner and outer rings on both ends as well as aligning the cone hole patterns from top to bottom. The Martin Marietta drill fixture is shown in Figure 4-14. Using this fixture, General Dynamics designed and fabricated the two alignment plates

Table 4-6. Summary of Dimensional Data on Cones 1 Through 5, Drawing 48125

Dimensions (inches)	Dwg 48125D Requirements	Cone 1	Cone 2	Cone 3	Cone 4	Cone 5
Base Diameter - Large End	7.79 ± 0.02	7.78	7.79	7.80	7.78	7.80
Base Diameter - Small End	5.80 ± 0.02	5.78	5.78	5.78	5.81	5.78
Concentricity of Rings - Both Ends	0.02	0.02	0.01	0.02	0.06†	0.02
Flatness - Small End	0.005	0.005	0.004	0.004	0.004	0.004
Parallelism of Ends	0.010	0.005	0.006	0.002	0.005	0.003
Flatness - Large End	0.005	0.005	0.005	0.001	0.005	0.002
Height	9.10 ± 0.03	9.11	9.10	9.10	9.105	9.10

†Deviation accepted by AMMRC - cone designated for testing in compression only.

Table 4-7. Summary of Test Results on Cones 1 Through 5, Drawing 48125 (Ref. 1)

Test	Loading Condition	Failure Load: Test	Failure Load: Analysis	Type of Failure
1	Compression	160,000 lb (axial comp)	166,000 lb (axial comp)	Overall compression failure at small end
2	Shear/bending	20,000 lb (shear)	31,300 lb (shear)	Localized interlaminar shear failure at large end
3	Combined load-simultaneous	180% design limit loads (DLL)	158% DLL	Overall compression failure at large end
4	Combined load-constant compression	53,334 lb axial comp + 180% DLL for other loads	53,334 lb axial comp +139% DLL for other loads	Overall compression failure at small end
5	Combined load-constant bending	64,662 in-lb bending moment at large end + 540% axial comp DDL	64,662 in-lb bending moment +700% axial comp DDL	Overall compression failure at small end

Figure 4-14. Martin Marietta Drill Fixture

shown in Figure 4-15, which were used to assure the proper relationship between inner and outer rings on both ends. These plates were useful when bonding rings on only one end of a cone, but were not useful in aligning the hole patterns from top to bottom. The Martin Marietta drill fixture was used as a bonding fixture for this latter task.

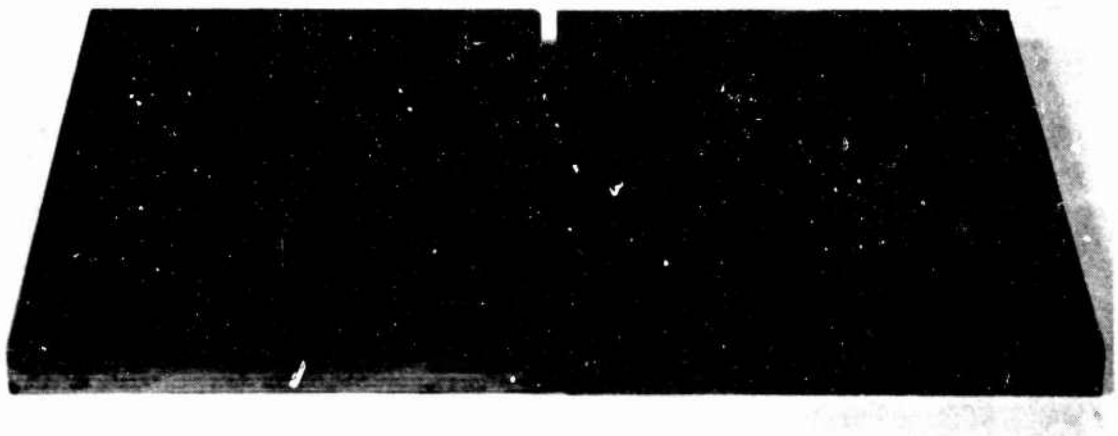


Figure 4-15. Alignment Plates

The rings used for the first five cones were stripped from the broken specimens by Martin Marietta and returned to General Dynamics for use on the second set of cones. A second variation was introduced for the ring bonding operation on the second set of five cones. To maintain concentricity between inner and outer rings, 0.022 in. copper wires (approximately 0.5 in. long) were bonded to the ring surfaces with quick setting epoxy adhesive. Four equally spaced wires were bonded vertically on each ring's adherend surface, with the wires approximately centered (leaving approximately 0.5 in. from the wire ends to the edge of the joints). The rings were then bonded to the shell in a manner similar to that used with the first batch of five cones. The cone fabrication procedure for the second set of five cones was identical to that previously described for the first five cones.

Two problems occurred during the assembly of cones 6 through 10. On cone 6, the upper rings were misaligned by 90 degrees with respect to the bottom rings. This occurred because of improper use of the bonding fixtures. This was corrected for cones 7 through 10. Cone 6, because of the hole alignment problem, was used for compression testing rather than combined load testing.

The low viscosity of the EA-9309 adhesive continued to cause assembly problems. On assembly, the adhesive would flow from the mating surface interface and leave an adhesive layer on the bottom of the rings. Also, small voids at the edge of the bonds would occur. The voids were secondarily filled with EA-9309, and the adhesive was removed from the ring faces by machining. In one case, sufficient adhesive flowed under a ring to cause cocking of the ring. This required taking an 0.069 in. cut off that end of the assembly to meet the flatness and parallelism requirements. The second set of five cones is shown in Figure 4-16. Table 4-8 is a summary of the quality control data on cones 6 through 10.

Table 4-9 is a summary of the testing conducted by Martin Marietta on cones 6 through 10. Again, the test results were extremely gratifying. If anything, the results on cones 6 through 10 were even better than those obtained on cones 1 through 5. There was good correlation between experimental and predicted results. The first five cones were made from prepreg lot 4E-20, while the second five cones were made from lot 4E-31. A review of the prepreg certification revealed that the GY-70 fiber used in lot 4E-20 had a higher average tensile strength than that used in lot 4E-31. However, some of the bobbins in both lots had approximately the same strength. Since basic cone processing remained the same, the improvements in failure loads are attributed to a combination of normal data scatter and slight improvements in flatness, parallelism, and concentricity of the assembled test specimens.

Sections of failed cones 7, 8, and 9 were obtained from Martin Marietta. Pieces of the cross sections from these cones were mounted and polished. Photomicrographs were obtained at 50X magnification. Typical photomicrographs are those shown in Figures 4-17 and 4-18. Examination revealed dense, uniform sections, essentially

Figure 4-16. Second Set of Five Cones

Table 4-8. Summary of Dimensional Data on Cones 6 Through 10, Drawing 48125

Dimensions (inches)	Dwg 48125D Requirements	Cone 6	7	8	9	10
Base Diameter - Large End	7.79 ± 0.02	7.785	7.785	7.785	7.780	7.780
Base Diameter - Small End	5.80 ± 0.02	5.785	5.810	5.805	5.805	5.790
Concentricity of Rings - Both Ends	0.02	0.02	0.02	0.02	0.02	0.02
Flatness - Small End	0.005	0.005	0.005	0.005	0.005	0.005
Parallelism of Ends	0.010	0.005	0.005	0.005	0.005	0.010
Flatness - Large End	0.005	0.005	0.005	0.005	0.005	0.005
Height	9.10 ± 0.03	9.095	9.085	9.085	9.095	9.085

Table 4-9. Summary of Test Result on Cones 6 Through 10, Drawing 48125 (Ref. 1)

Test	Loading Condition	Failure Load: Test	Failure Load: Analysis	Type of Failure
6	Compression	180,000 lb (axial comp)	166,000 lb (axial comp)	Overall compression failure at small end
7	Combined load-simultaneous	200% DLL	158% DLL	Compression failure at large end
8	Combined load-constant compression	80,000 lb axial comp + 150% DLL for other loads*	80,000 lb axial comp + 104% DLL for other loads*	Compression failure at small end
9	Combined load-constant bending moment at large end	64,662 in-lb bending moment at large end + 720% axial comp DLL	64,662 in-lb bending moment + 700% axial comp DLL	Compression failure at small end
10	Combined load-constant compression	150,000 lb axial comp + 170% DLL for other loads*	150,000 lb axial comp + 175% DLL for other loads*	Localized interlaminar shear and bond failure at large end

*Other loads are bending moment, shear and lateral pressure loads.

void free, and without microcracks. A typical gore butt joint is seen in Figure 4-18, and it appears as a local resin-rich area. This butt joint appears to be 0.055 in. in actual size. Resin contents of cones 7, 8, and 9 were determined to be 35.20, 33.85, and 32.40% by weight, respectively. This corresponds to fiber volumes of 54.85, 56.37, and 57.93% respectively.

4.2 CONICAL FRUSTA WITH JOINT REINFORCEMENTS

A shell reinforcement evaluation was conducted by Martin Marietta (Reference 1) to determine the most efficient bolted designs for a maximum design load of 5100 lb/in. This study included three designs of interleaved titanium foils, a high-strength graphite/epoxy reinforced section, a fiberglass cloth reinforced epoxy built-up section, and a Kevlar-49 cloth reinforced epoxy built-up section. The study showed that only the interleaved titanium foil designs were efficient and practical. The study was reviewed by AMMRC and General Dynamics and accepted with some minor modifications.

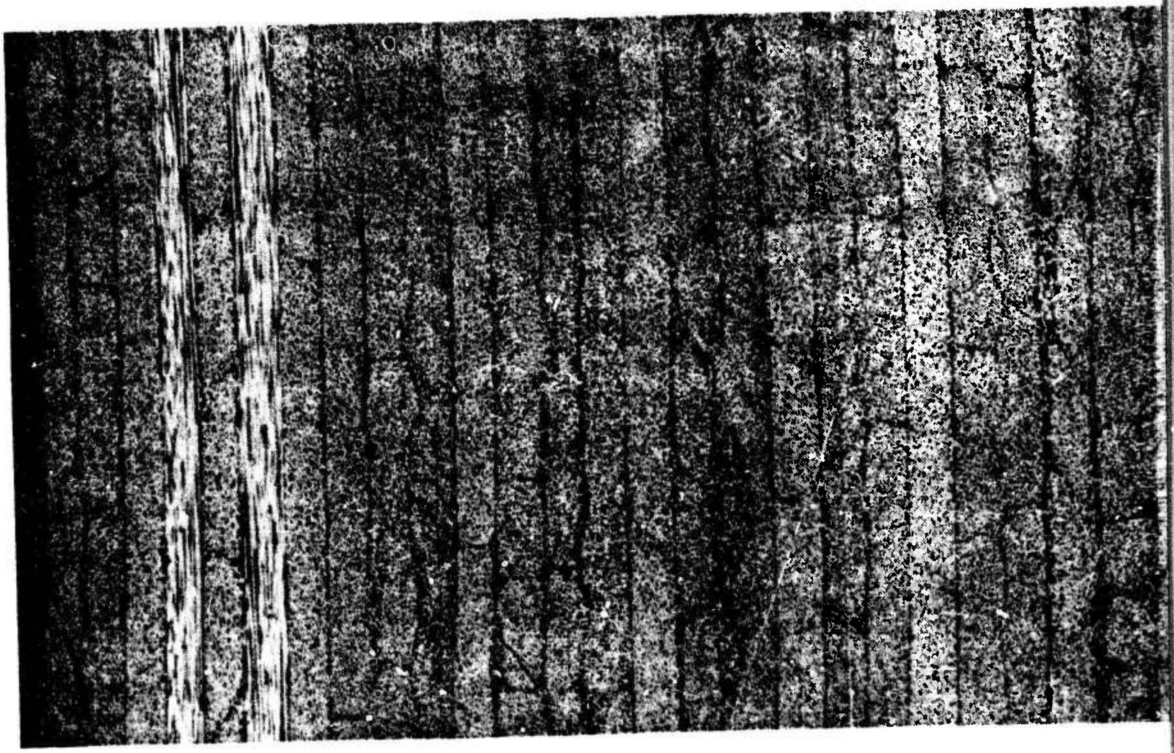


Figure 4-17. Photomicrog

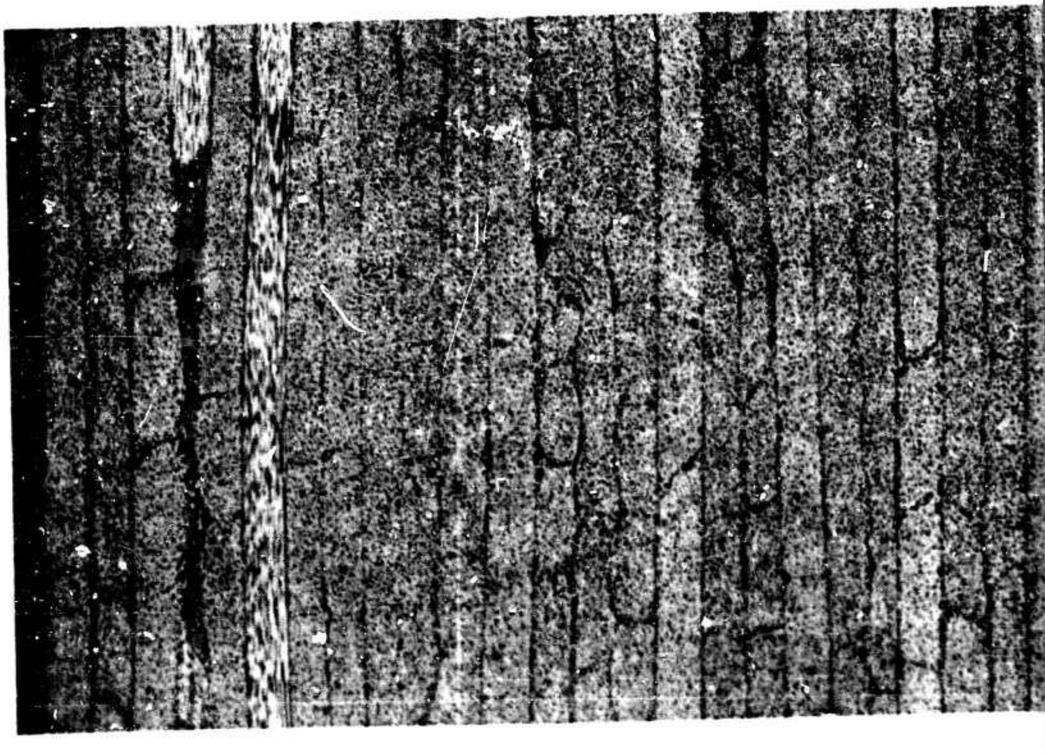


Figure 4-18. Photomicrog

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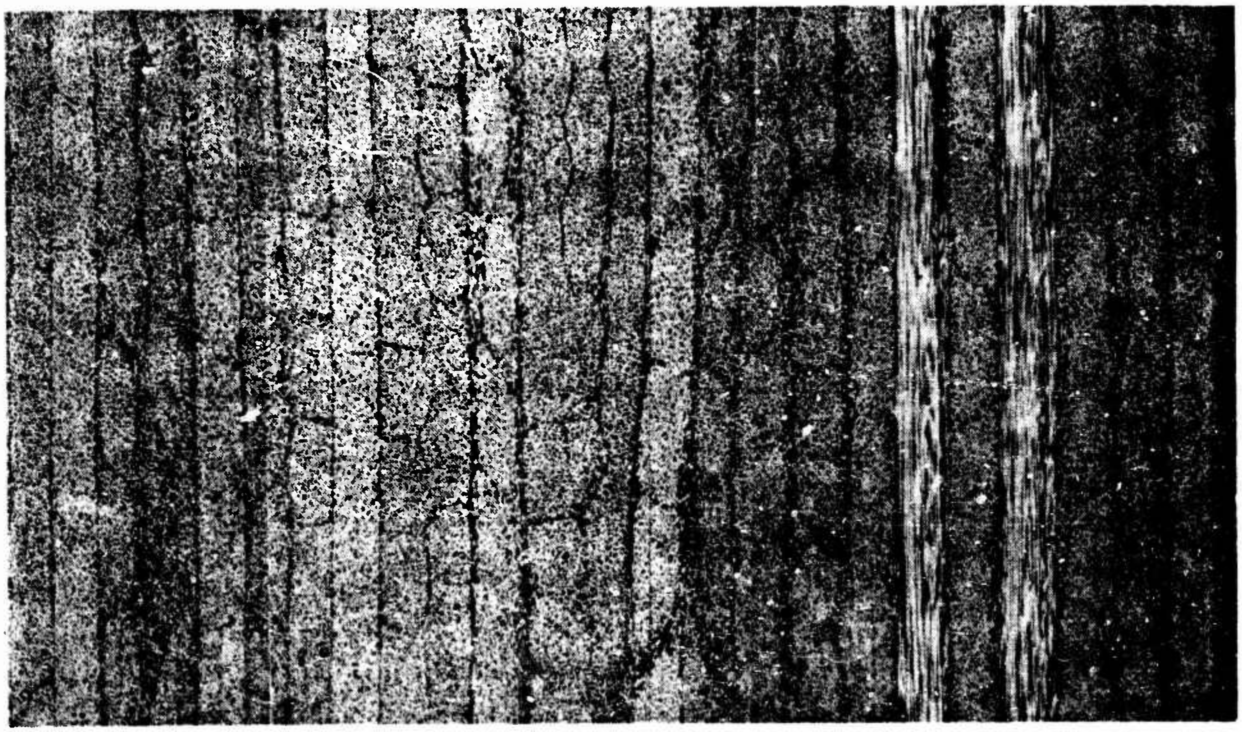

Figure 4-17. Photomicrograph of Cone 8 Cross-Section at 50X

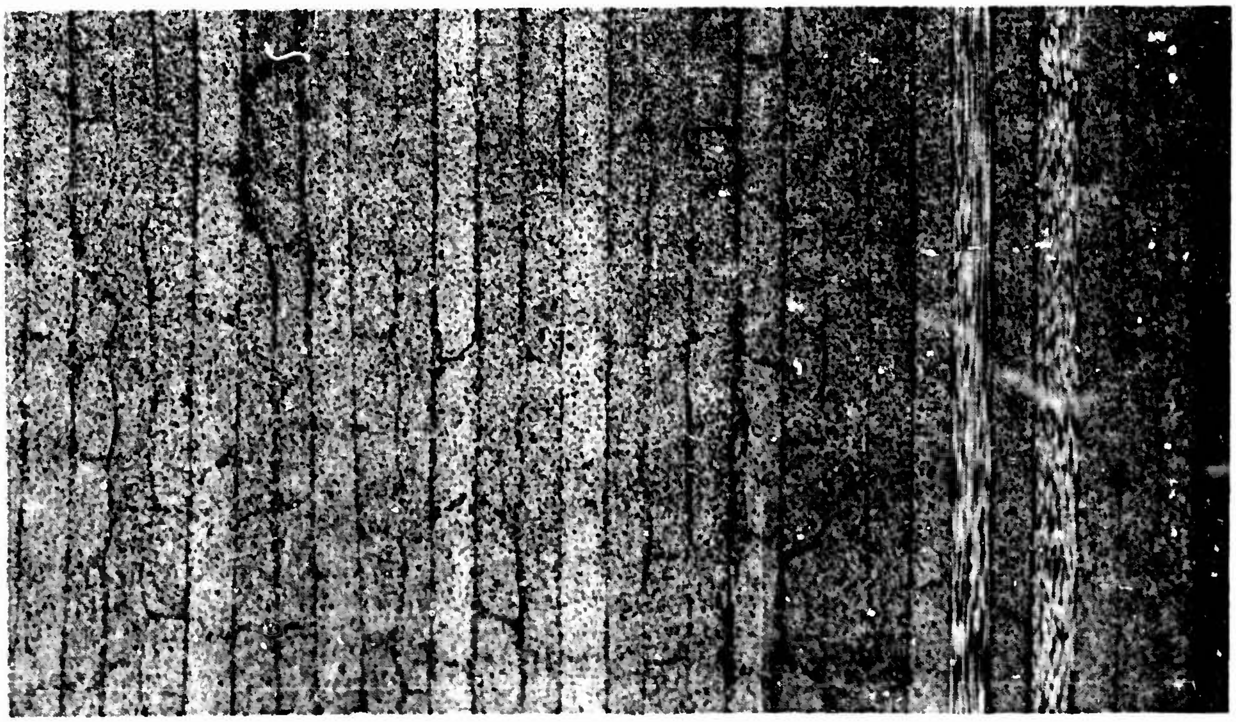

Figure 4-18. Photomicrograph of Cone 9 Cross-Section at 50X

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Because of the complexity of the interleaved titanium foil joints, a flat panel evaluation program was conducted first. The Martin Marietta joint design conical shell specimens are shown in Figure 4-19. The flat panel program was conducted using joint design 1. The flat specimen configurations are shown in General Dynamics Drawing 72C0596 (Figure 4-20). The splice pattern of the titanium and graphite/epoxy prepreg was designed to correspond to that proposed for the conical shell joint specimens. The graphite/epoxy used in the panel was GY-70/934, lot 4E-31, roll 21, and the layup was identical to that proposed in Figure 4-19 for design 1. The titanium foil was 0.0075 in. annealed 6Al-4V titanium coil stock, 9.312 in. wide, obtained from Teledyne Rodney Metals. The foil was shipped to Chemical Machining, El Segundo, California for chemical milling of a hole pattern. The pattern selected was 0.020 in. diameter holes on 0.4 in. centers. The purpose of these holes was to facilitate resin and volatile bleeding during layup and cure.

The test panel per Drawing 72C0596 was layed up and cured in a picture frame tool. Figure 4-21 shows both the tool and the finished panel. A 38-ply control panel was prepared and cured using the same prepreg (lot 4E-31, roll 21). Reduced section tensile specimens were prepared and the test results gave an average tensile strength of 62.2 ksi, an average tensile modulus of 27.7 msi, and an average resin content by weight of 29.50%. The latter corresponds to an average fiber volume of 61.44%. Tensile strength and modulus values normalized to 63% fiber volume are 63.8 ksi and 284 msi, respectively. These results are what would normally be anticipated from good GY-70/934 prepreg. During the same time period a 12-ply unidirectional laminate was also prepared from prepreg lot 4E-31, roll 21. Average test results on this panel were: tensile strength 124.8 ksi, tensile modulus 45.7 msi, and resin content 27.90 weight percent. The calculated average fiber volume was 63.27%. Tensile strength and modulus values normalized to 63% fiber volume were 124.3 ksi and 45.5 msi respectively.

Thickness measurements on the cured joint panel showed that the panel was very uniform. In the joint area, thicknesses varied from 0.269 to 0.279 in. In the reduced section, thicknesses varied from 0.196 to 0.200 in. These were in excellent agreement with nominal drawing dimensions. Three specimens of the three types shown on Drawing 72C0596, i.e., tension, transition compression, and joint compression, were machined from the joint test panel.

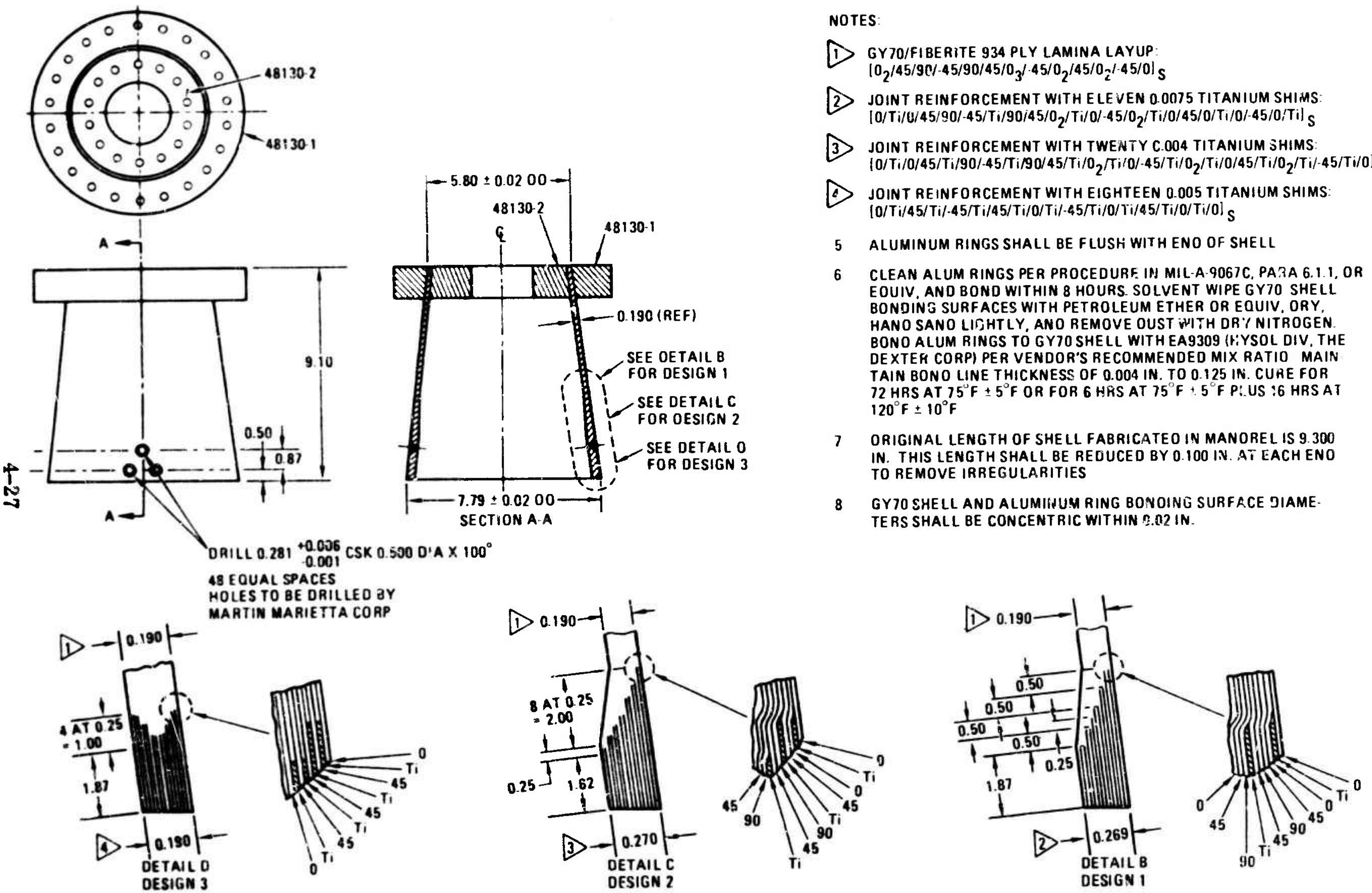

Figure 4-19. Martin Marietta Joint Designs for Conical Shell Specimens (Drawing 48126)

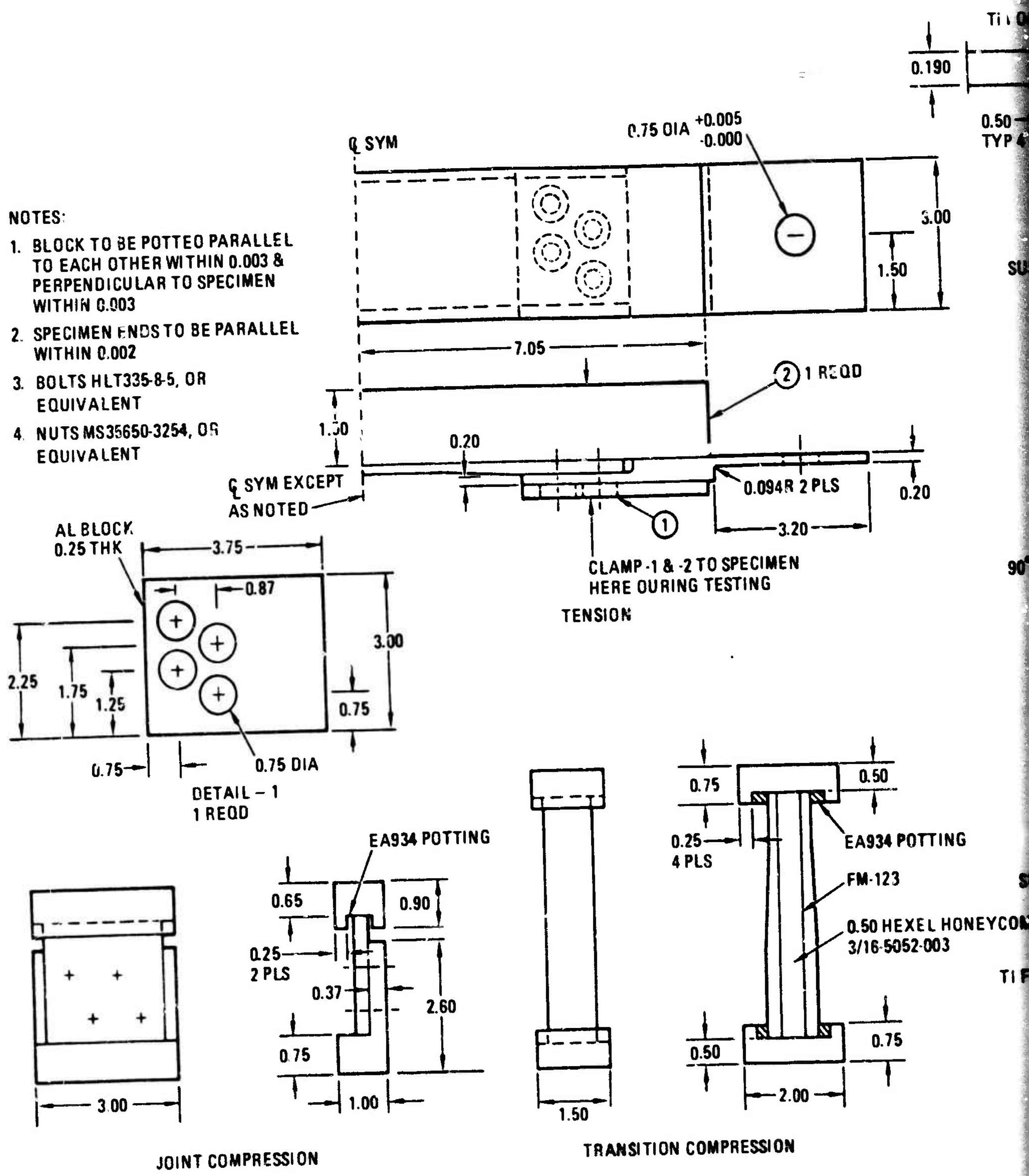

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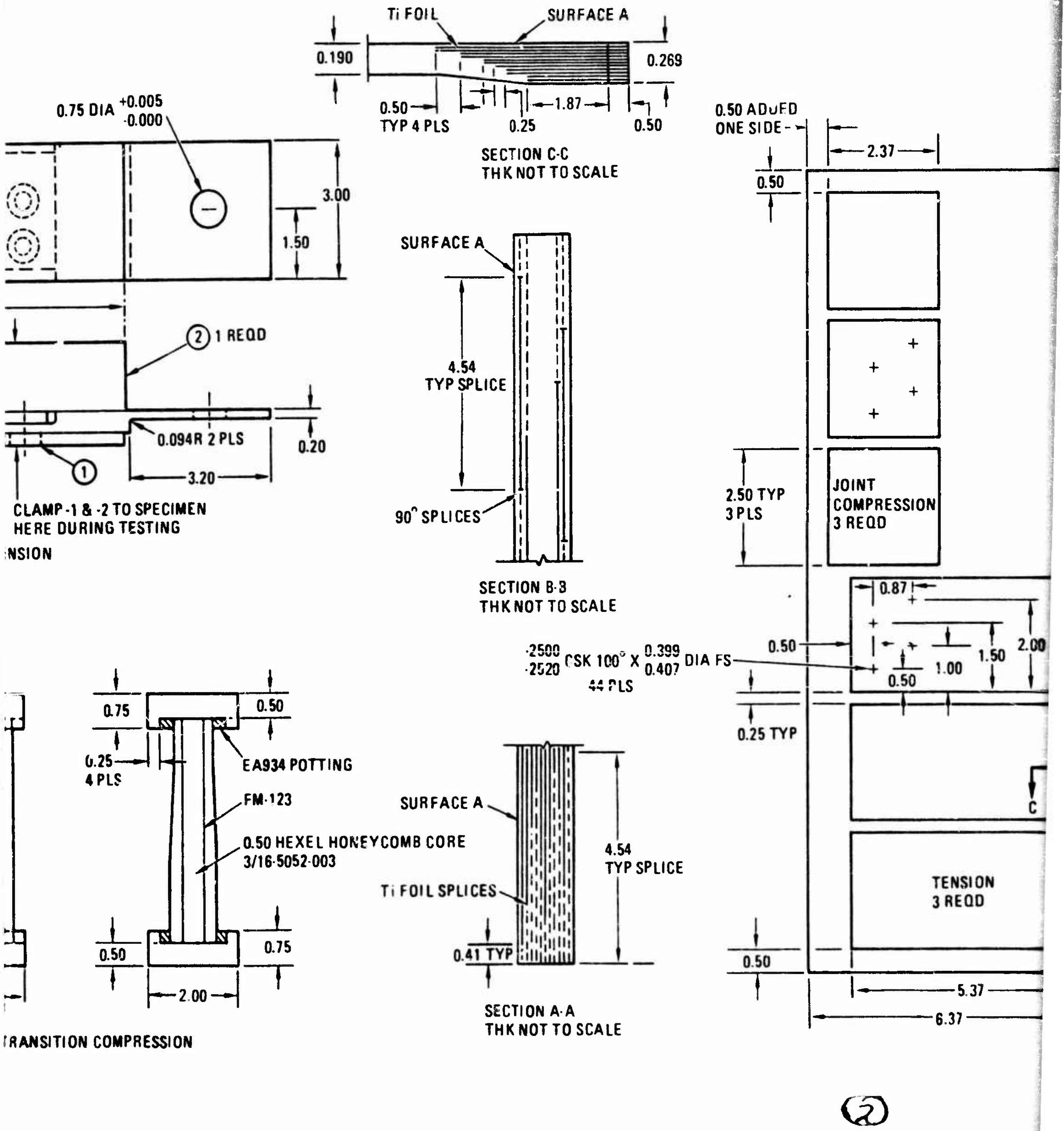
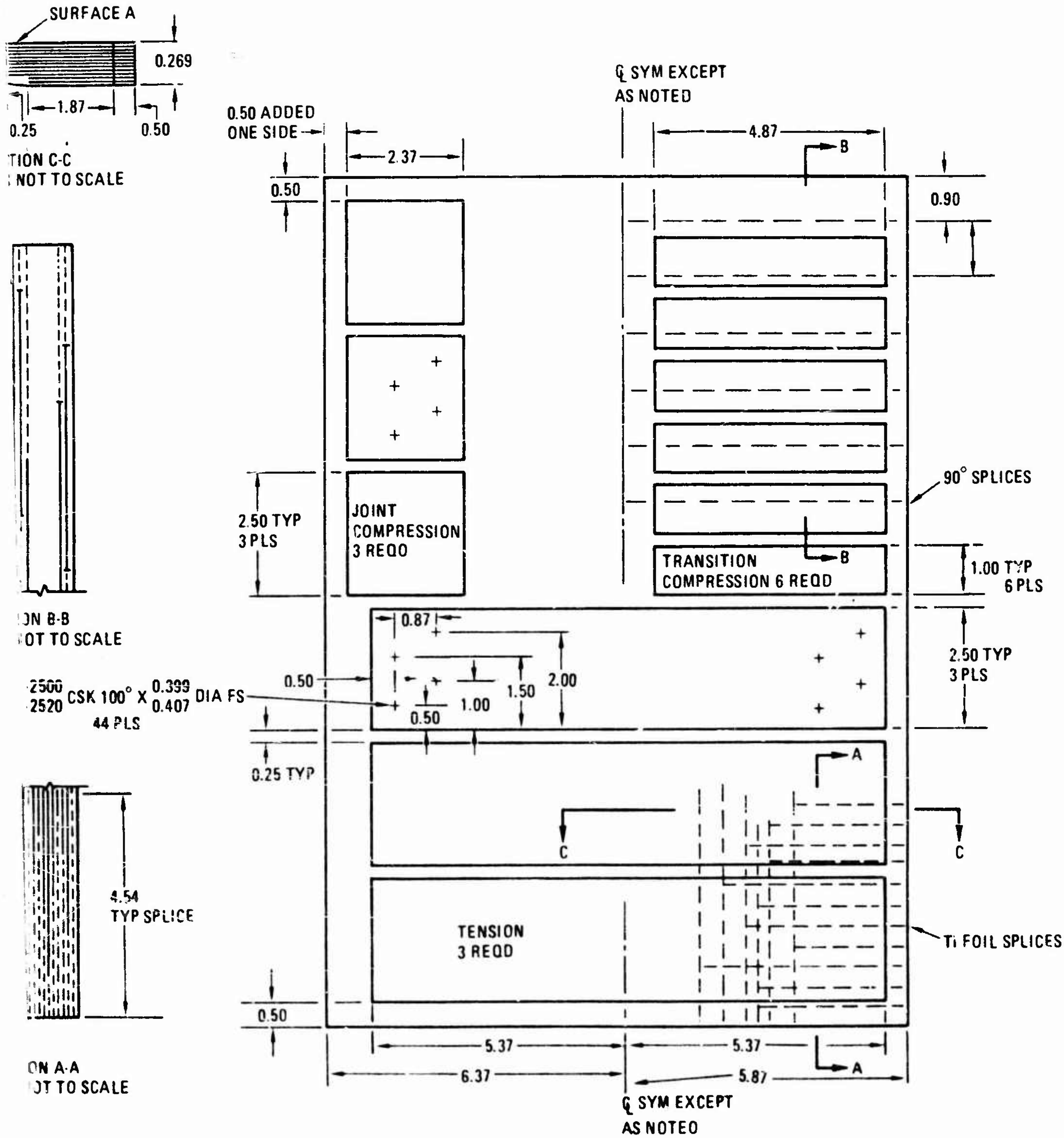
Figure 4-20. Flat Specimen Configurations (Drawing 72C0596)



ations (Drawing 72C0596)



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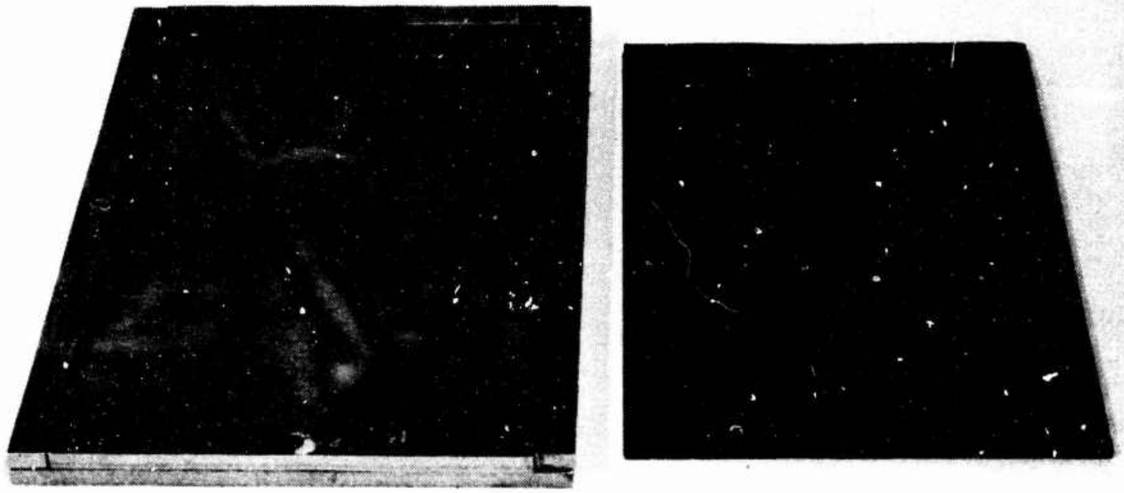


Figure 4-21. Curing Tool and Finished Panel

The transition compression specimens were prepared by bonding the facings to 0.50 in. thick Hexcel 1/8-5052-002 aluminum honeycomb core having a density of 8.1 lb/ft^3. The facings were bonded one at a time using Hysol's EA-9314 epoxy adhesive and were cured at room temperature. The ends of the specimens were ground flat and parallel prior to potting. The specimens were potted into high strength steel channel test fixtures using Hysol's EA-934 adhesive and cured at room temperature. The specimens were loaded to failure in compression at room temperature. Figure 4-22 shows the three specimens after test. The 1.0-in. wide specimens failed at ultimate loads of 19,200; 19,200; and 19,450 lb. The results were consistent, and the failure mode was the same for all three specimens. Failures occurred at the nonreinforced ends. Figure 4-23 shows the typical failure pattern. The first mode of failure was delamination several plies in from the outer faces, and this was followed by a net compression failure across the facings. This test proved that the joint was stronger in compression than the basic shell configuration.

The joint compression specimens were machined, and the bolt holes were drilled and countersunk to match the holes in the L-shaped test fixture. The specimens were potted into high-strength steel channel test fixtures per the configuration shown in Drawing 72C0596 using Hysol's EA-934 adhesive and a room temperature cure. The specimens were bolted to the L-shaped test fixture using NAS 1478-10 huck bolts and NAS 1080-C08 collars. The maximum gap between the bottom of the bolted specimen and the bearing surface on the L-shaped fixture was about 5 mils. This was purposely designed into the test specimens to simulate drilling tolerances likely to be encountered in testing the conical shell joint specimens. The gap closed rapidly during test of the

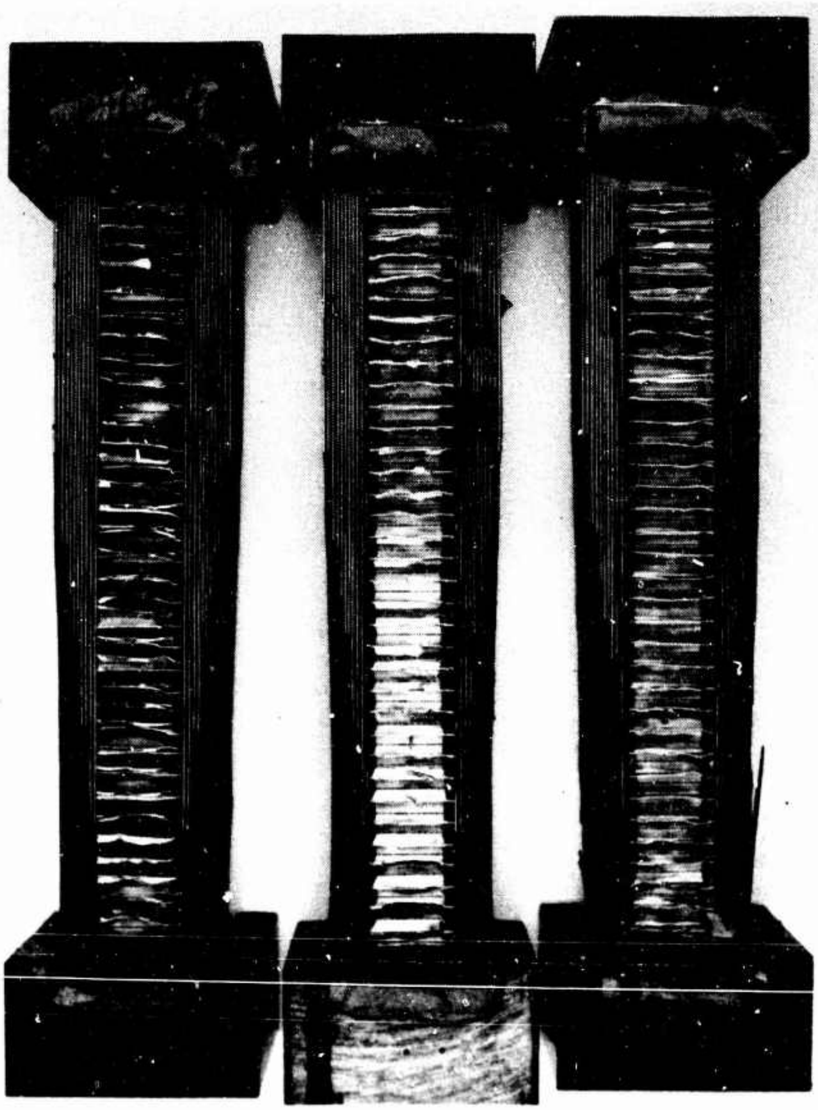


Figure 4-22. Transition Compression Specimens After Test

joint compression specimens. The specimens were tested to failure at room temperature. The failure loads for the 2.5-in. wide specimens were 34,850; 36,900; and 34,350 lb. The failure mode was localized buckling at the potted end of the specimen with localized delamination occurring within the laminate in several planes at the same end of the specimen. Figure 4-24 shows an edge view of typical failed specimen. Figure 4-25 shows a front view of the specimen after failure has occurred. The required joint strength was 7650 lb/in (design load of 5100 lb/in with a safety factor of 1.5). The average failure load for the compression specimens was 14,150 lb/in, which greatly exceeded the ultimate requirements.

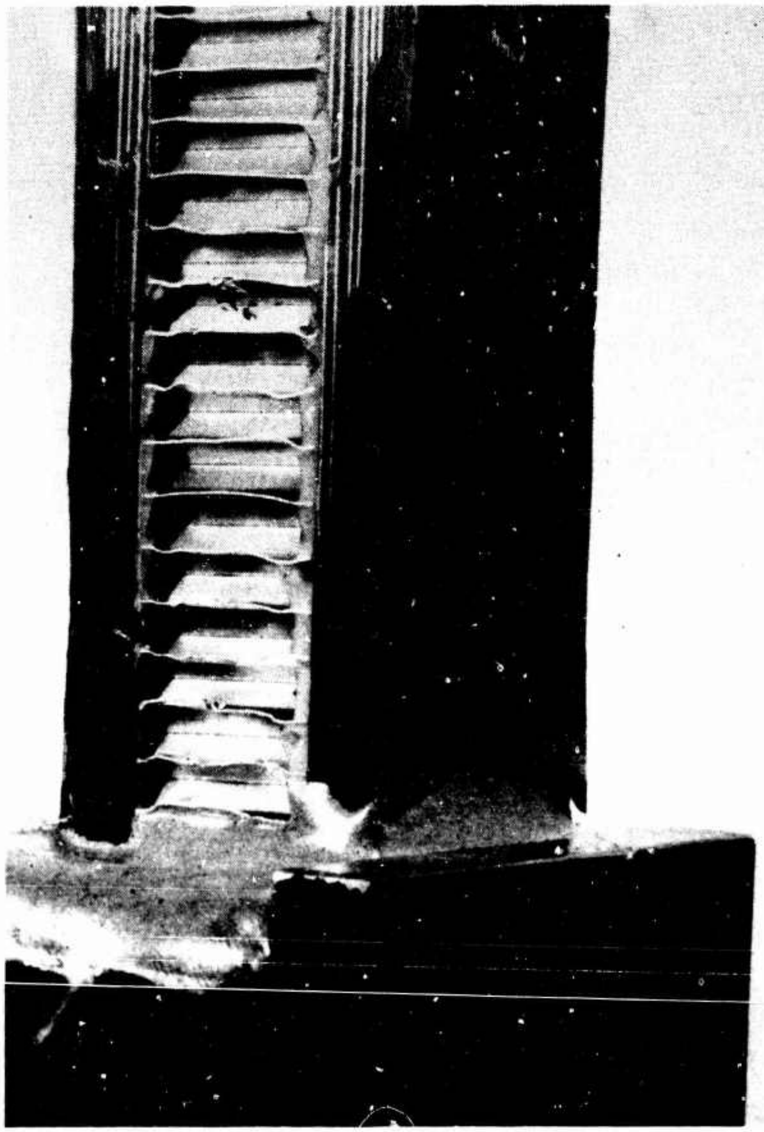


Figure 4-23. Typical Failure Pattern of Transition Compression Specimens

The tension joint specimens were machined per Drawing 72C0596. A typical 2.5-in. wide specimen is shown in Figure 4-26. The specimens were bolted to steel clevises as shown in Figure 4-27 using NAS 1154 bolts and MS21043-4 nuts. Washers were used under the nuts to accommodate the excess length of the bolts. The bolts were torqued to 180 in-lb. Aluminum blocks were loosely clamped to the clevises and test specimen during each test as a means of minimizing rotation. Aluminum foil shims were placed between the test specimen and the long aluminum block to assure localized contact over the full length of the test specimen. Hysol EA-934 adhesive was used as a liquid shim in the clevis areas to assure contact between specimen and test fitting.

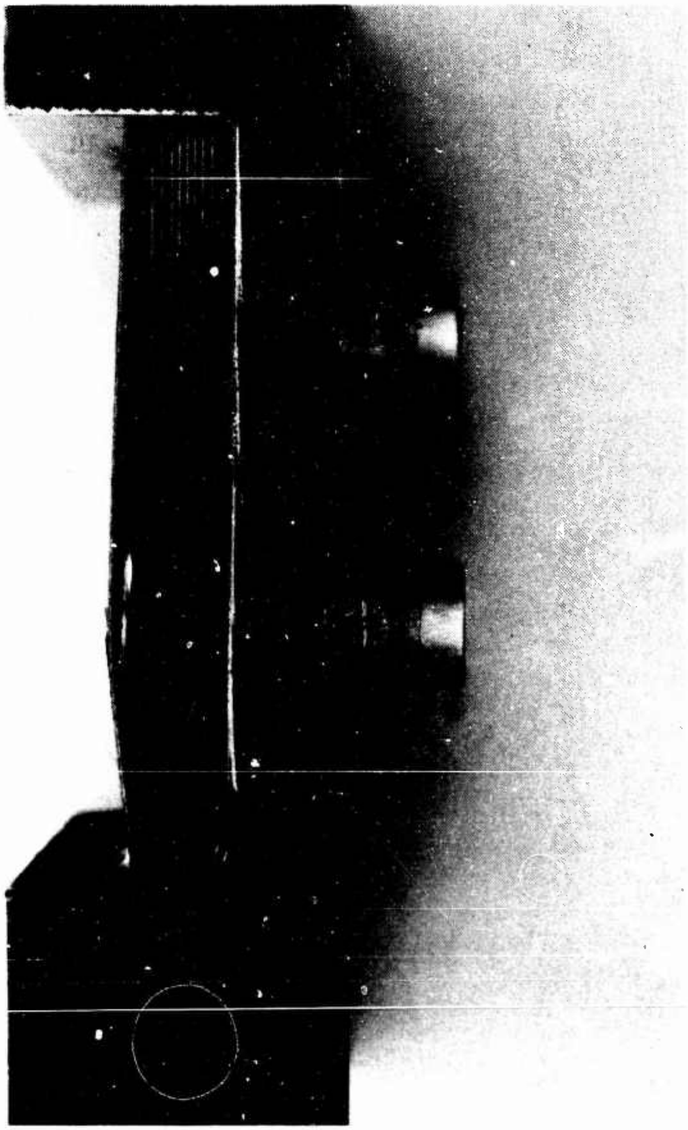


Figure 4-24. Edge View of Typical Failed Specimen

All three tensile specimens failed in a similar manner at similar ultimate loads. The initial failure was accompanied by a loud cracking noise. The specimens loaded beyond the initial failing load and then held at a fairly constant load indicating some local yielding (hole elongation). Initial failing loads for the three specimens were 17,000; 16,500; and 16,900 lb. Final yielding loads for the three specimens were 19,100; 19,250; and 19,600 lb. This gives an average failure onset load of 6720 lb/in and an average yielding load or ultimate failure load of 7730 lb/in. The average ultimate load exceeded the required joint strength of 7650 lb/in.

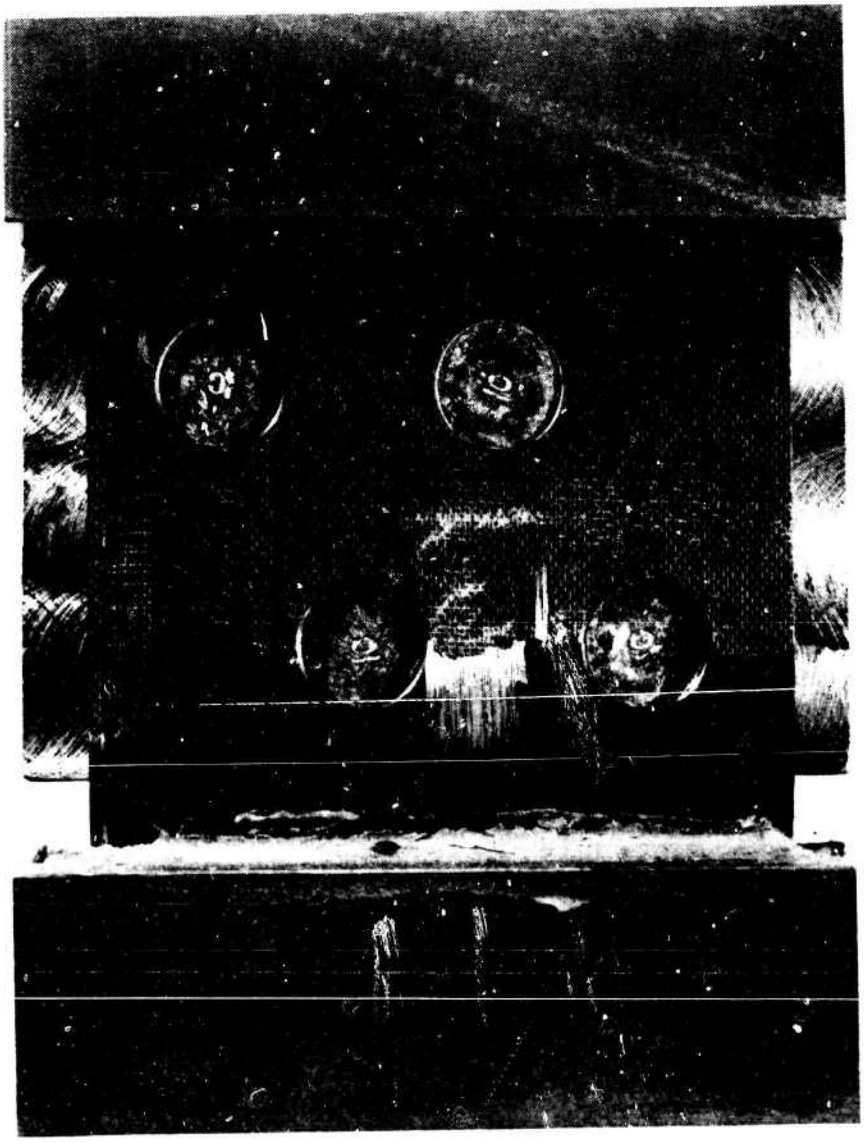


Figure 4-25. Front View of Specimen After Failure

The failed tensile specimens all showed excessive bolt hole elongation. Rotation of the bolt heads caused local bulging of the composite. Some shear-out of bolts was also encountered. Figure 4-28 shows the bolt hole elongation and shear-out. Figure 4-29 shows onset of failure on the face of the specimen. It can be seen that the bolts have started to rotate, and the light spots show localized bulging of the composite. The bolts were removed from the failed specimens, and Figure 4-30 shows the typical distortion encountered.

A review of all the flat joint specimen testing confirmed the adequacy of the joint design for conical shell specimens. This left only the manufacturing procedures and cone fabrication to be demonstrated.

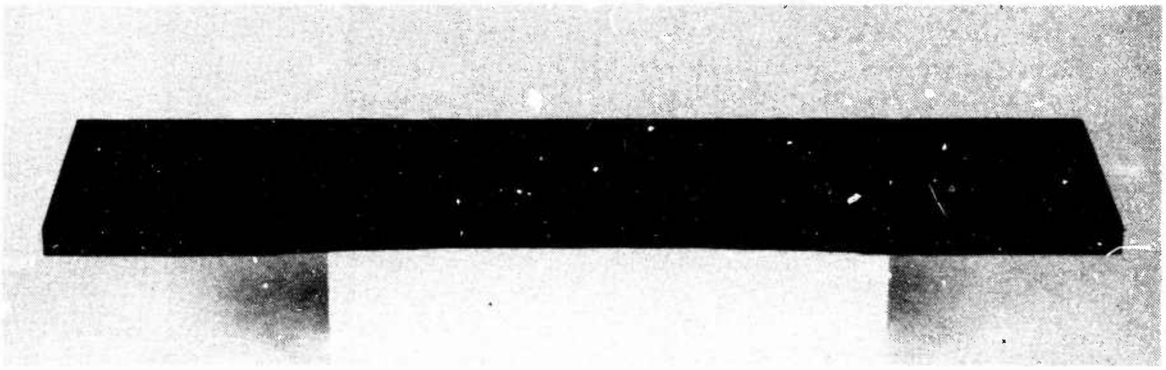


Figure 4-26. Typical 2.5-in. Wide Tension Joint Specimen

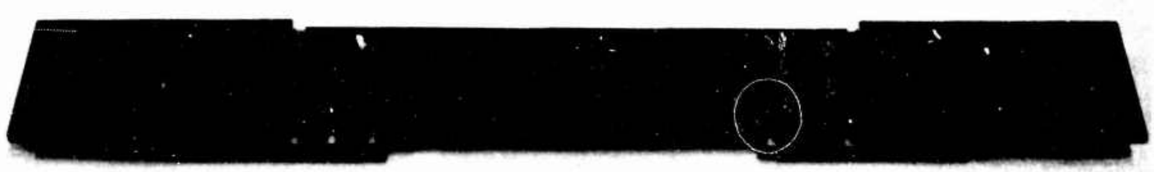


Figure 4-27. Specimens Bolted to Clevises

For the reinforced joint cone frusta specimens (graphite/epoxy and interleaved titanium foil) typified by designs 1, 2, and 3 on Drawing 48126, the method of construction is essentially identical to that used for the non-reinforced specimens. Only the additional layers of titanium and the small changes in individual gore size are different for these reinforced specimens. As seen in Figures 4-31 through 4-33, separate tabulations of individual gore size requirements were made for the three joint designs. Table 4-10 summarizes gore template dimensions. It was not necessary to have a separate template for each gore. The criterion previously used for the non-reinforced specimens was continued whereby gores representative of

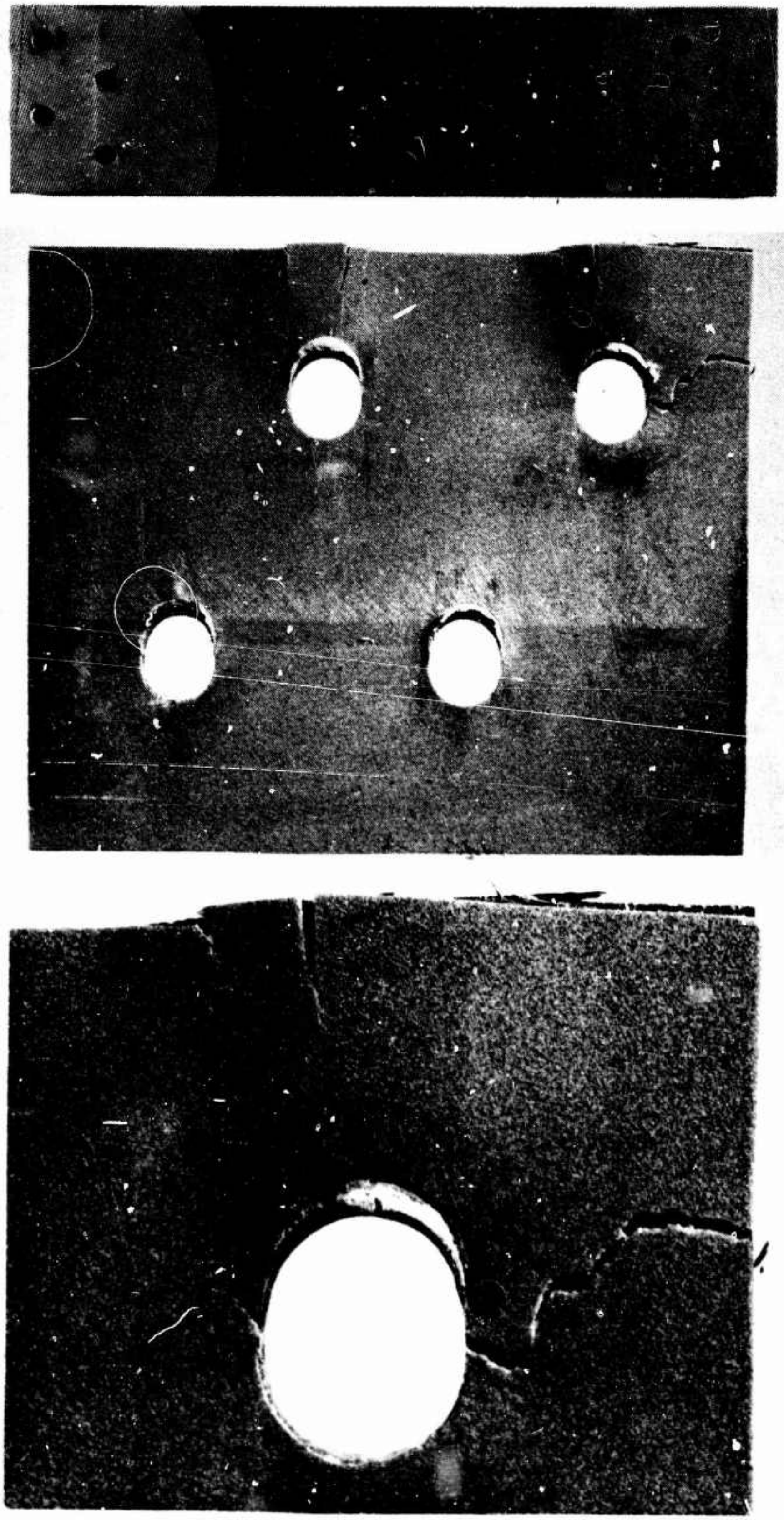


Figure 4-28. Bolt Hole Elongation and Shear-out in Specimens

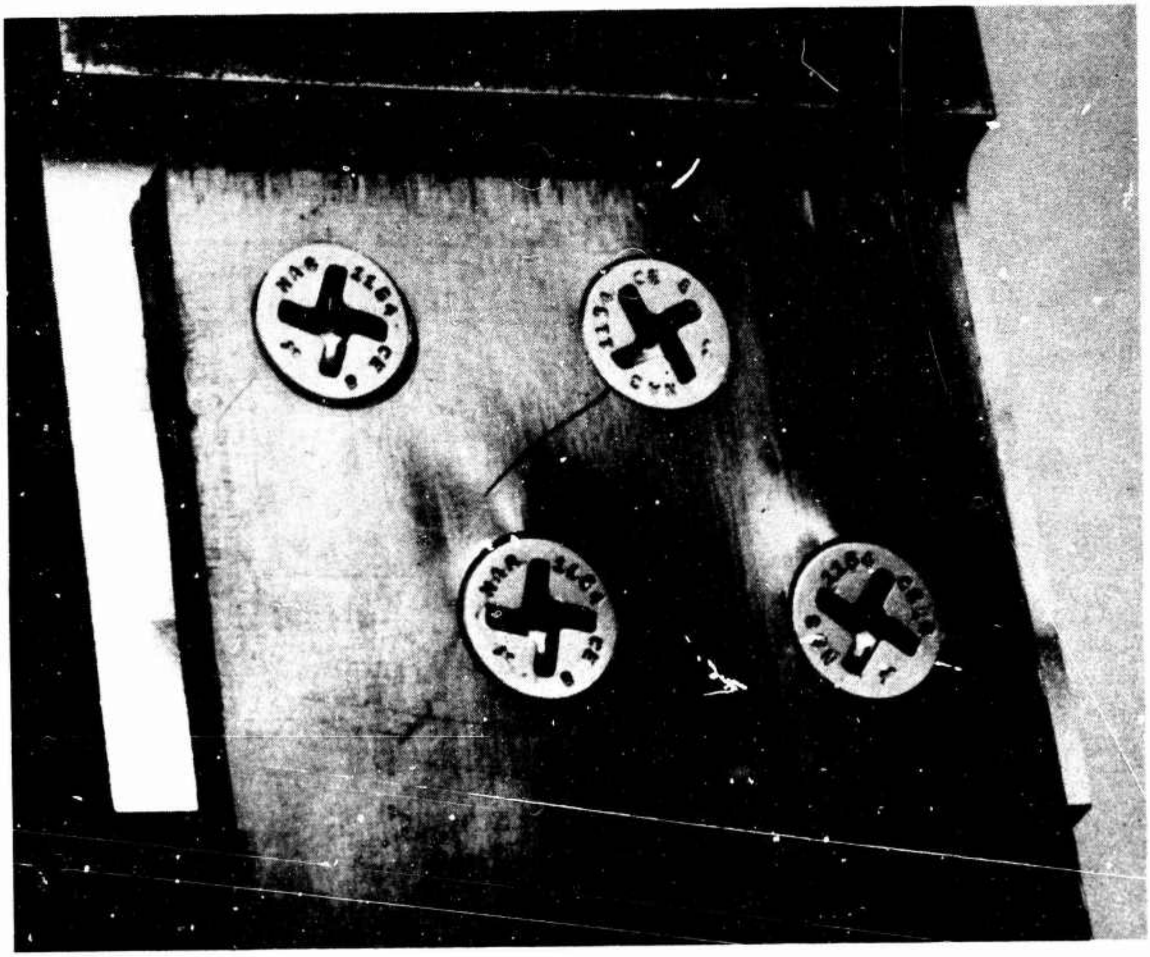


Figure 4-29. Onset of Failure on Face of Specimen

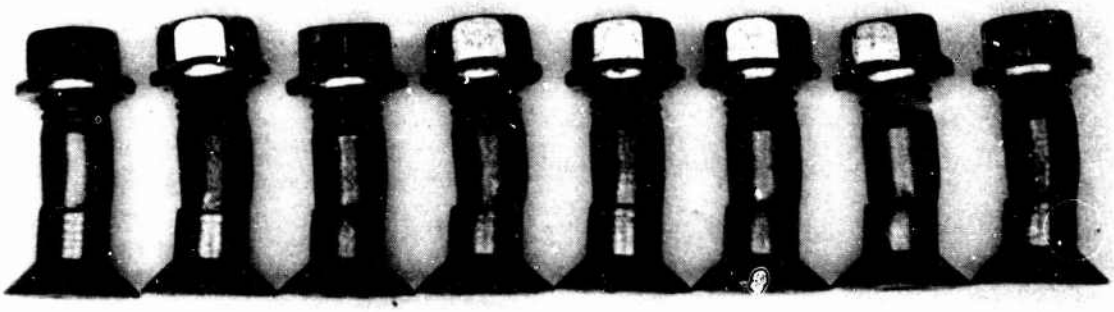
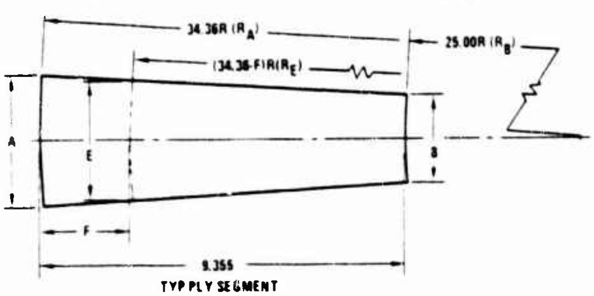


Figure 4-30. Typical Distortion of Bolts

Ply No.	$t_{G/E}$	t_{Ti}	$D_A = 7.81 - 2t_{G/E} - 2t_{Ti}$	$D_B = 5.78 - 2t_{G/E}$	$D_E = 6.94 - 2t_{G/E} - 2t_{Ti}$ Ref	D_E Variable	A $\pi D/4, 12$	B $\pi D/4, 12$	E	Orientation	Wrap Angle	α	Template No.	
1	.01	-	7.790	5.76	6.920		2.039	1.507		0	30	0° 0'	1	
2	-	.0075	7.775	-	6.905	6.905	2.034	-	1.807	Ti	30	3° 15'	13	
3	.01	-	7.755	5.74	6.885		2.029	1.502		0	30	18° 30'	1	
4	.01	-	7.735	5.72	6.865		6.072	4.490		45	90	[illegible]° 0'	7	
5	.01	-	7.715	5.70	6.845		6.056	4.475		90	90	25° 30'	7	
6	.01	-	7.695	5.68	6.835		6.041	4.459		-45	90	13° 45'	7	
7	-	.0075	7.680	-	6.810	6.810	2.010	-	1.782	Ti	30	26° 30'	13	
8	.01	-	7.660	5.66	6.790		6.013	4.443		90	90	2° 15'	8	
9	.01	-	7.640	5.64	6.770		5.887	4.427		45	90	20° 45'	8	
10	.01	-	7.620	5.62	6.750		1.994	1.471		0	30	9° 15'	2	
11	.01	-	7.600	5.60	6.730		1.988	1.466		0	30	27° 45'	2	
12	-	.0075	7.585	-	6.825	6.825	1.984	-	1.785	Ti	30	10° 15'	14	
13	.01	-	7.565	5.58	6.805		1.979	1.460		0	30	16° 15'	2	PRE
14	.01	-	7.545	5.56	6.785		5.923	4.365		-45	90	4° 30'	11	PLY
15	.01	-	7.525	5.54	6.765		1.969	1.450		0	30	23° 0'	3	
16	.01	-	7.505	5.52	6.745		1.963	1.445		0	30	11° 30'	3	
17	-	.0075	7.490	-	6.730	6.730	1.959	-	1.761	Ti	30	3° 15'	14	
18	.01	-	7.470	5.50	6.710		1.954	1.439		0	30	0° 0'	3	
19	.01	-	7.450	5.48	6.690		5.848	4.302		45	90	18° 30'	11	
20	.01	-	7.430	5.46	6.670		1.944	1.429		0	30	7° 0'	4	
21	-	.0075	7.415	-	6.765	6.765	1.940	-	1.770	Ti	30	26° 30'	15	
22	.01	-	7.395	5.44	6.745		1.935	1.424		0	30	27° 30'	4	
23	.01	-	7.375	5.42	6.725		5.759	4.255		-45	90	13° 45'	12	PRE
24	.01	-	7.355	5.40	6.705		1.924	1.413		0	30	2° 15'	5	BLEED
25	-	.0075	7.550	-	6.885	6.885	1.975	-	1.801	Ti	30	10° 15'	15	TO 0.103
26	.01	-	7.530	5.54	6.865		1.970	1.450		0	30	20° 45'	3	THICK
27	.01	-	7.510	5.52	6.845		5.897	4.333		-45	90	9° 15'	11	
28	.01	-	7.490	5.50	6.825		1.959	1.439		0	30	27° 45'	3	
29	-	.0075	7.475	-	6.720	6.720	1.955	-	1.758	Ti	30	3° 15'	16	
30	.01	-	7.455	5.48	6.700		1.950	1.434		0	30	16° 15'	4	
31	.01	-	7.435	5.46	6.680		5.837	4.286		45	90	4° 30'	11	
32	.01	-	7.415	5.44	6.660		1.940	1.424		0	30	23° 0'	4	
33	-	.0075	7.400	-	6.786	6.786	1.936	-	1.775	Ti	30	26° 30'	17	
34	.01	-	7.380	5.42	6.766		1.931	1.418		0	30	11° 30'	4	
35	.01	-	7.360	5.40	6.746		1.925	1.413		0	30	6° 0'	5	
36	.01	-	7.340	5.38	6.726		5.762	4.223		-45	90	18° 30'	12	
37	.01	-	7.320	5.36	6.706		1.915	1.403		0	30	7° 0'	5	PRE
38	-	.0075	7.305	-	6.691	6.691	1.911	-	1.750	Ti	30	10° 15'	17	
39	.01	-	7.285	5.34	6.671		1.906	1.397		0	30	27° 30'	5	
40	.01	-	7.265	5.32	6.651		1.90[illegible]	1.392		0	30	13° 45'	5	
41	.01	-	7.245	5.30	6.631		5.687	4.161		45	90	2° 15'	9	
42	.01	-	7.225	5.28	6.611		5.672	4.145		90	90	20° 45'	9	
43	-	.0075	7.210	-	6.705	6.705	1.886	-	1.734	Ti	30	3° 15'	18	
44	.01	-	7.190	5.26	6.685		5.644	4.129		-45	90	9° 45'	10	
45	.01	-	7.170	5.24	6.665		5.628	4.113		90	90	27° 45'	10	
46	.01	-	7.150	5.22	6.645		5.613	4.098		45	90	16° 15'	10	
47	.01	-	7.130	5.20	6.625		1.867	1.361		0	30	4° 30'	6	
48	-	.0075	7.115	-	6.610	6.610	1.861	-	1.729	Ti	30	26° 30'	18	
49	.01	-	7.095	5.18	6.590		1.856	1.356		0	30	23° 0'	6	
														FINAL CURE

NOTE.
SEE TABLE 4-10 FOR TEMPLATE GEOMETRY (DIMENSIONAL VALUES).



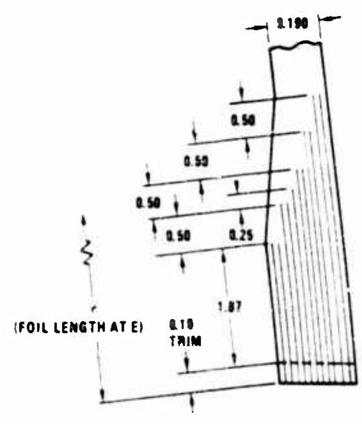


Figure 4-31. Layup Configuration for Joint Design 1 Cones, Drawing 48126

	Ply No.	$t_{G/E}$	t_{Ti}	D_A = 7.81-2$t_{G/E}$-2t_{Ti}	D_B = 5.78-2$t_{G/E}$	D_E = 6.94-2$t_{G/E}$-27 $t_{G/E}$ Ref.	D_E Variable	A	B	E	Orientation	Wrap Angle	α	Template No.	
	1	.01	-	7.79	5.76	6.92	-	2.038	1.507	-	0	30	0° 0'	1	
	2	-	.004	7.78	-	6.91	6.91	2.035	-	1.810	Ti	30	3° 15'	13	
	3	.01	-	7.76	5.74	6.89		2.029	1.502	-	0	30	18°30'	1	
	4	.01	-	7.74	5.72	6.87		6.075	4.490	-	45	90	7° 0'	7	
	5	-	.004	7.73	-	6.86	6.86	2.022	-	1.795	Ti	30	10°15'	13	
	6	.01	-	7.71	5.70	6.84		6.054	4.475	-	90	90	25 30'	7	
	7	.01	-	7.69	5.68	6.82		6.043	4.459	-	-45	90	13°45'	7	
	8	-	.004	7.68	-	6.84	6.84	2.010	-	1.789	Ti	30	17° 0	23	
	9	.01	-	7.66	5.66	6.82		6.013	4.443	-	90	90	2° 15'	8	
	10	.01	-	7.64	5.64	6.80		5.987	4.427	-	45	90	20°45'	8	
	11	-	.004	7.63	-	6.79	6.79	1.996	-	1.776	Ti	30	26 30	23	
	12	.01	-	7.61	5.62	6.77		1.991	1.471	-	0	30	9 15'	2	
	13	.01	-	7.59	5.60	6.75		1.986	1.466	-	0	30	27 45'	2	
	14	-	.004	7.59	-	6.83	6.83	1.986	-	1.790	Ti	30	5 45'	14	
	15	.01	-	7.57	[illegible]	6.81		1.980	1.460	-	0	30	16 15'	2	PRE
△	16	.01	-	7.55	5.56	6.79		5.925	4.367	-	-45	90	4° 30'	11	PLY
	17	-	.004	7.54	-	6.78	6.78	1.973	-	1.774	Ti	30	19 30	14	
	18	.01	-	7.52	5.54	6.76		1.965	1.450	-	0	30	23° 0'	3	
	19	.01	-	7.50	5.52	6.74		1.960	1.445	-	0	30	11 30	3	
	20	-	.004	7.49	-	6.79	6.79	1.959	-	1.776	Ti	30	21 45'	24	
	21	.01	-	7.47	5.50	6.77		1.954	1.439	-	0	30	0° 0	3	
△	22	.01	-	7.45	5.48	6.75		5.848	4.302	-	45	90	18 30'	11	
	23	-	.004	7.44	-	6.74	6.74	1.940	-	1.763	Ti	30	3° 15'	24	
	24	.01	-	7.42	5.46	6.72		1.943	1.429	-	0	30	7° 0'	4	
	25	.01	-	7.40	5.44	6.70		1.937	1.424	-	0	30	25 30'	4	
	26	-	.004	7.39	-	6.74	6.74	1.933	-	1.763	Ti	30	10 15'	15	
△	27	.01	-	7.37	5.42	6.72		5.786	4.255	-	-45	90	13 45'	15	
	28	-	.004	7.37	-	6.72	6.72	1.928	-	1.758	Ti	30	17 0	25	
	29	.01	-	7.35	5.40	6.70		1.920	1.413	-	0	30	2° 15'	[illegible]	PRE
	30	.01	-	7.33	5.38	6.68		1.918	1.407	-	0	30	20 45'	[illegible]	BLEED
	31	-	.004	7.50	-	6.90	6.90	1.965	-	1.807	Ti	30	26 30'	26	TO 0.103
△	32	.01	-	7.48	5.56	6.88		5.872	4.365	-	-45	90	9 15'	11	THICK
	33	-	.004	7.47	-	6.87	6.87	1.954	-	1.797	Ti	30	5 45'	26	
	34	.01	-	7.45	5.54	6.85		1.950	1.450	-	0	30	27 45'	19	
	35	.01	-	7.43	5.52	6.83		1.944	1.445	-	0	30	16° 15'	19	
	36	-	.004	7.42	-	6.88	6.88	1.943	-	1.800	Ti	30	19 30	17	
△	37	.01	-	7.40	5.50	6.86		5.810	4.320	-	45	90	4 30	17	
	38	.01	-	7.38	5.48	6.84		1.931	1.434	-	0	30	23° 0'	19	
	39	-	.004	7.37	-	6.83	6.83	1.928	-	1.787	Ti	30	21 45'	17	
	40	.01	-	7.35	5.46	6.81		1.920	1.429	-	0	30	11°30	20	
	41	.01	-	7.33	5.44	6.79		1.918	1.424	-	0	30	0 0	20	
	42	-	.004	7.33	-	6.84	6.84	1.918	-	1.789	Ti	30	3 15	27	
△	43	.01	-	7.31	5.42	6.82		5.738	4.255	-	-45	90	18 30	17	
	44	.01	-	7.29	5.40	6.80		1.910	1.413	-	0	30	7 0	20	PRE
	45	-	.004	7.28	-	6.79	6.79	1.904	-	1.776	Ti	30	10 15'	[illegible]	PLY
	46	.01	-	7.26	5.38	6.78		1.900	1.407	-	0	30	25 30	[illegible]	
	47	.01	-	7.24	5.36	6.76		1.894	1.402	-	0	30	13 45'	[illegible]	
	48	-	.004	7.23	-	6.80	6.80	1.891	-	1.779	Ti	30	17 0	18	
	49	.01	-	7.21	5.34	6.78		5.610	4.192	-	45	90	2 15	16	
	50	.01	-	7.19	5.32	6.76		5.644	4.176	-	90	90	20 45	16	
	51	-	.004	7.18	-	6.75	6.75	1.878	-	1.766	Ti	30	26 30	18	
	52	.01	-	7.16	5.30	6.73		5.621	4.161	-	-45	90	9 15'	16	
	53	.01	-	7.14	5.28	6.71		5.605	4.145	-	90	90	27°45'	16	
	54	-	.004	7.13	-	6.75	6.75	1.865	-	1.766	Ti	30	5 45'	28	
	55	.01	-	7.11	5.26	6.73		5.581	4.129	-	45	90	16 15'	29	
	56	.01	-	7.09	5.24	6.71		1.859	1.370	-	0	30	4 30'	22	
	57	-	.004	7.09	-	6.71	6.71	1.859	-	1.755	Ti	30	19 30'	28	
	58	.01	-	7.07	5.22	6.69		1.850	1.366		0	30	23 0	22	FINAL CURE

NOTE:
SEE TABLE 4-10 FOR TEMPLATE GEOMETRY (DIMENSIONAL VALUES)

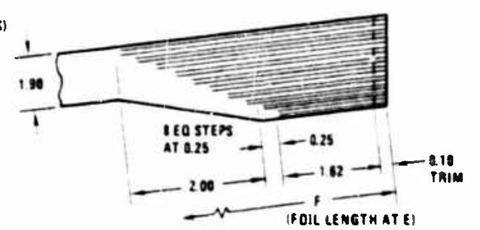


Figure 4-32. Layup Configuration for Joint Design 2 Cones, Drawing 48126

	Ply No.	A	B	Length of Graphite/ Epoxy	Orien- tation	Wrap Angle	α	Template No.	
	1	2.040	1.510	9.355	0	30	0° 0'	1	
	2	2.035	1.505	6.832	0/Ti	30	18° 30'	1	
	3	6.090	4.495	9.355	+45	90	7° 0'	7	
	4	6.075	4.480	6.382	90/Ti	90	25° 30'	7	
	5	6.060	4.465	9.355	-45	90	13° 30'	7	
	6	6.045	4.450	6.632	-90/Ti	90	2° 15'	7	
	7	6.030	4.435	9.355	+45	90	20° 45'	7	
	8	2.005	1.475	6.632	0/Ti	30	9° 15'	2	
	9	2.000	1.470	9.355	0	30	27° 45'	2	
	10	1.995	1.465	6.882	0/Ti	30	16° 15'	2	PRE
△	11	5.970	4.375	9.355	-45	90	4° 30'	31	PLY
	12	1.985	1.455	6.882	0/Ti	30	23° 0'	2	
	13	1.980	1.450	9.355	0	30	11° 30'	2	
	14	1.975	1.445	7.132	0/Ti	30	0° 0'	3	
△	15	5.911	4.317	9.355	+45	90	17° 30'	11	
	16	1.965	1.435	7.132	0/Ti	30	7° 0	3	
	17	1.960	1.430	9.355	0	30	25° 30'	3	
△	18	5.866	4.272	7.382	-45/Ti	90	13° 45'	11	PRE
	19	1.950	1.420	9.355	0	30	2° 15'	4	BLEED
	20	1.985	1.455	9.355	0	30	20° 45'	2	TO 0.103
△	21	5.942	4.343	7.382	-45/Ti	90	9° 15'	11	THICK
	22	1.975	1.445	9.355	0	30	27° 45'	2	
	23	1.970	1.440	7.132	0/Ti	30	16° 15'	3	
△	24	5.897	4.303	9.355	+45	90	4° 30'	11	
	25	1.960	1.430	7.132	0/Ti	30	23° 0'	3	
	26	1.955	1.425	9.355	0	30	11° 30	3	
	27	1.950	1.420	6.882	0/Ti	30	0° 0'	4	
△	28	5.836	4.242	9.355	-45	90	18° 30'	12	
	29	1.940	1.410	6.882	0/Ti	30	7° 0'	4	PRE
	30	1.935	1.405	9.355	0	30	25° 30'	4	PLY
	31	1.930	1.400	6.632	0/Ti	30	13° 45'	4	
	32	5.778	4.185	9.355	+45	90	2° 15'	30	
	33	5.764	4.170	6.632	90/Ti	90	20° 45'	30	
	34	5.740	4.155	9.355	-45	90	9° 15'	30	
	35	5.735	4.140	6.382	90/Ti	90	27° 45'	30	
	36	5.720	4.125	9.355	+45	90	16° 15'	30	
	37	1.900	1.370	6.382	0/Ti	30	4° 30'	5	
	38	1.895	1.365	9.355	0	30	23° 0'	5	
									FINAL CURE

NOTE
SEE TABLE 4-10 FOR TEMPLATE GEOMETRY (DIMENSIONAL VALUES)

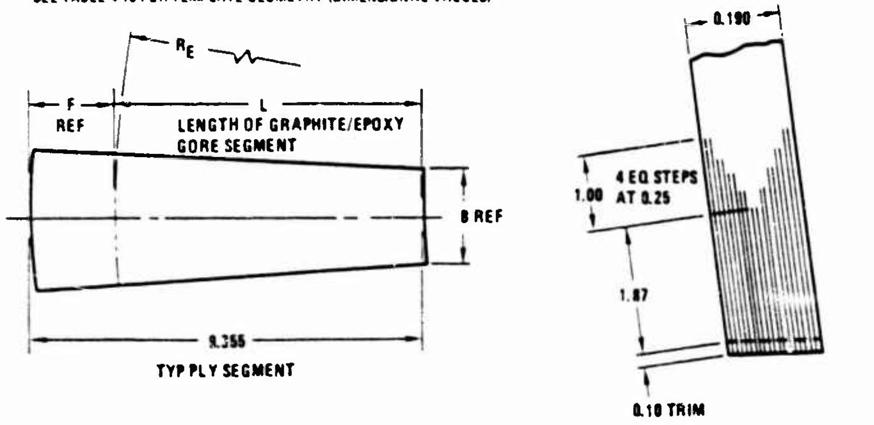


Figure 4-33. Layup Configuration for Joint Design 3 Cones, Drawing 48126

Table 4-10. Dimensions of Gore Templates

Template No.	A	B	E	F	R_A	R_B	R_E
1	2.400	1.510	-	-	34.36	25.00	-
2	2.000	1.470	-	-	34.36	25.00	-
3	1.970	1.450	-	-	34.36	25.00	-
4	1.950	1.430	-	-	34.36	25.00	-
5	1.930	1.410	-	-	34.36	25.00	-
6	1.870	1.360	-	-	34.36	25.00	-
7	6.070	4.490	-	-	34.36	25.00	-
8	6.010	4.440	-	-	34.36	25.00	-
9	5.690	4.160	-	-	34.36	25.00	-
10	5.640	4.130	-	-	34.36	25.00	-
11	5.920	4.370	-	-	34.36	25.00	-
12	5.790	4.260	-	-	34.36	25.00	-
13	2.030	-	1.810	3.97	34.36	-	30.39
14	1.980	-	1.790	3.47	34.36	-	30.89
15	1.980	-	1.800	2.97	34.36	-	31.39
16	1.960	-	1.760	2.72	34.36	-	31.64
17	1.940	-	1.780	2.47	34.36	-	31.89
18	1.890	-	1.750	1.97	34.36	-	32.39
19	1.950	1.450	-	-	34.36	25.00	-
20	1.920	1.430	-	-	34.36	25.00	-
21	1.900	1.410	-	-	34.36	25.00	-
22	1.860	1.370	-	-	34.36	25.00	-
23	2.100	-	1.790	3.72	34.36	-	30.64
24	1.960	-	1.780	3.22	34.36	-	31.14
25	1.930	-	1.760	2.97	34.36	-	31.39
26	1.970	-	1.810	2.72	34.36	-	31.64
27	1.920	-	1.790	2.22	34.36	-	32.14
28	1.870	-	1.770	1.72	34.36	-	32.64
29	5.610	4.150	-	-	34.36	25.00	-
30	5.780	4.190	-	-	34.36	25.00	-
31	5.970	4.380	-	-	34.36	25.00	-

several different ply layers are cut by the same template. This criterion is based on dimensional changes that occur as plies are laid into a female tool. Progressively smaller and smaller gores, which butt together, are required in order to complete any one layer since the inside diameter gets smaller with each subsequent layer. Here the criterion is that the first gore size to exactly fit into the tool, one gore butted to the other, establishes the size of the template. Subsequent gores will tend to be oversize and will require the last gore of these layers to be cut to fit. The criterion established was that the excess cut from this last gore must be less than 0.25 in. Another (smaller) template is required when this criterion is about to be exceeded. This next smaller template is designed to provide gores that exactly fit for the next scheduled ply. The various template numbers called out in Table 4-10 illustrate this procedure. In effect, they have been analytically determined. Where precompaction of the layers is called for and a change in internal diameter occurs, a reversion back to previously used (larger) templates is necessary.

The thickness added by the titanium is, of course, accounted for in all calculations and templates were also used for marking and cutting the titanium foil. The titanium was used as 30-degree gores to allow expansion within the layer during precompaction and final cure. The titanium gores were sized in the same manner as was the graphite/epoxy. It was also decided to let the titanium foil extend to the edge of the tool and trim the 0.10 in. off the cured cones as before.

The manufacturing procedure used for building the all graphite/epoxy cones was modified for the manufacture of cones 1 to 6 per Drawing 48126, joint design 1. The modified manufacturing procedure is given below.

1. Lay up sufficient large sheets of unidirectional GY-70/934 to prepare all gores needed for layup of one cone. Note batch and roll numbers of all prepreg used in layup.

2. Remove flanges from bulk graphite tool. Apply Frekote 33 to tool and bake for one hour at 300F. Attach protractors to front and back ends of tool.

3. Cut titanium gores from 0.0075-in. thick 6Al-4V foil sufficient for all plies needed for layup of one cone.

4. Clean titanium by immersion in solution of Oakite-HD126 (106 gm/2.5 gallons of water) at 140 to 180F for 5 to 15 minutes. Rinse with tap water at RT to 180F.

5. Pickle titanium for two minutes maximum in solution of 2.0 to 3.0 fluid ounces/gallon HNO_3 at RT. Rinse pieces with tap water at RT. Immerse pieces for 1.5 to 2.5 minutes at RT in a solution of 6.5 to 7.0 ounces/gallon Na_3PO_4, 2.5 to 3.0 ounces/gallon of KF, and 2.2 to 2.5 fluid ounces/gallon of 70% HF. Rinse in tap water and follow with a 15 minute soak in deionized water at 145 to 155F.

6. Lay up plies 1 to 3 in tool per Figure 4-31.

7. Apply one ply of porous Teflon-coated glass cloth separator, envelope bag with Vac-Pak or equivalent film, and hold at RT under vacuum for a minimum of 15 minutes.

8. Lay up plies 4 to 6 in tool per Figure 4-31, and repeat step 7.

9. Lay up plies 7 to 10 in tool per Figure 4-31.

10. Install end rings and apply bleeder system consisting of one ply of porous Teflon-coated glass separator and three plies of style 7581 glass cloth. Apply silicone rubber overpress and two plies of style 1534 glass cloth as a vacuum vent. Install two thermocouples in trim areas of layup. Envelope bag with Vac-Pak or equivalent film.

11. Precompact as follows: apply a minimum vacuum of 24 in. of mercury on bag at RT; heat in autoclave at 2 to 5F/minute to 160±5F; apply 50-psig autoclave pressure and hold for 15 to 20 minutes; cool under vacuum and pressure to below 100F at a maximum rate of 5F/minute.

12. Vent and debag. Remove ring flanges and install protractors.

13. Lay up plies 11 to 15 in tool per Figure 4-31, and repeat step 7.

14. Lay up plies 16 to 19 in tool per Figure 4-31, and repeat step 7.

15. Lay up plies 20 to 23 in tool per Figure 4-31, and repeat steps 10 to 12.

16. Lay up plies 24 to 31 in tool per Figure 4-31, and repeat step 7.

17. Lay up plies 32 to 36 in tool per Figure 4-31, and repeat steps 10 to 12.

18. Lay up plies 37 to 44 in tool per Figure 4-31 and repeat step 7.

19. Lay up plies 35 to 49 in tool per Figure 4-31.

20. Install end rings and apply bleeder system consisting of one ply of porous Teflon-coated glass cloth separator film, one ply of style 120 glass cloth, and two plies of style 1534 glass cloth. Apply rubber overpress and two plies of style 1534 glass cloth as a vacuum vent. Install two thermocouples in trim areas of layup. Envelope bag with Vac-Pak or equivalent film.

21. Cure as follows: apply a minimum vacuum of 24 in. of mercury on bag at RT, and hold for a minimum of 30 minutes before heating; heat part in autoclave at a rate of 2 to 4F/minute to 250 ±10F; hold at 250 ±10F for 45 ±5 minutes, and then apply 100 ±5 psig autoclave pressure in less than 5 minutes; hold an additional 45 ±5 minutes at temperature and pressure; raise temperature to 350 ±10F at 2 to 4F/minute; hold at temperature and pressure for a minimum of two hours; cool at a rate not to exceed 10F/minute (pressure and vacuum optional).

22. Debag and remove part from tool.

23. Trim 0.1 inch from each end of cone frusta to conform with Drawing 48126.

24. Mask outside of cone frusta in areas not to be bonded. Sand lightly inside and outside of cone at small end where rings are to be bonded. Use Scotchbrite pads for sanding.

25. Solvent clean bond areas with methylethylketone or trichloroethane. Dry for a minimum of 30 minutes prior to bonding.

26. Rings machined per Drawing 48130 (Figure 4-8) shall be etched and bonded per Drawing 48126. The adhesive used shall be Hysol's EA - 9309 with a minimum cure of 24 hours at RT between successive ring bonding operations.

27. Inspect dimensions of finished cone per Drawing 48126.

Cones 1 and 2 per Drawing 48126 were prepared per the above manufacturing procedure. The titanium cleaning and etching procedure had previously been used successfully in the flat panel joint specimen test program. During the trimming operation on the first cone, several delaminations occurred on the large end of the cone. The No. 49 ply split in several places at the edges of butting titanium gores for various lengths up to 2.0 inches. This was accompanied by delaminations between plies No. 47 and No. 48 for lengths up to approximately 1.0 inch at the large end of the cone. This resulted in triangular shaped disbonds. In addition, some chipping of ply No. 49 occurred. Repairs were made with Hysol's EA-9412 capillary adhesive. After solvent cleaning and adhesive application, the disbonded sections were clamped and cured at RT. This was followed by a one hour cure at 150F. The chipped areas were also coated with adhesive to prevent further splintering. The titanium foil plies No. 2 and No. 48 were visible in local areas on the outside and inside of the cone, respectively. This type of cosmetic problem is illustrated in Figure 4-34. An edge view of the repaired cone is shown in Figure 4-35.

To minimize the machining problem and prevent the cosmetic problem, it was decided to move the outer titanium plies. For cones 3 to 6 per Drawing 48126, the following layup was used.

$$(0_2/45/Ti/90/-45/Ti/90/45/0_2/Ti/0/-45/0_2/Ti/0/45/0/Ti/0/-45/0/Ti)_s$$

No further problems were encountered in machining in cones manufactured per joint design 1, Drawing 48126. Inspection data on cones 1 to 6 per Drawing 48126 is summarized in Table 4-11. Wall thickness measurements were made on the six cones around the periphery at three locations; i.e., 1) plane one-half inch from the small diameter, 2) center plane of cone, and 3) plane one-half inch from the large diameter. Measurements were made every 90 degrees at the three planes, with some intermediate measurements on cone 48126-1. Table 4-12 summarizes the wall thickness measurements. The measurements display a small range for each individual cone, with a larger variation from cone to cone. This may be a result of prepreg thickness variations from roll to roll. The overall range at the small end of the cones was from 0.183 to 0.200 in. with an average for the 24 measurements of 0.191 in. At the center

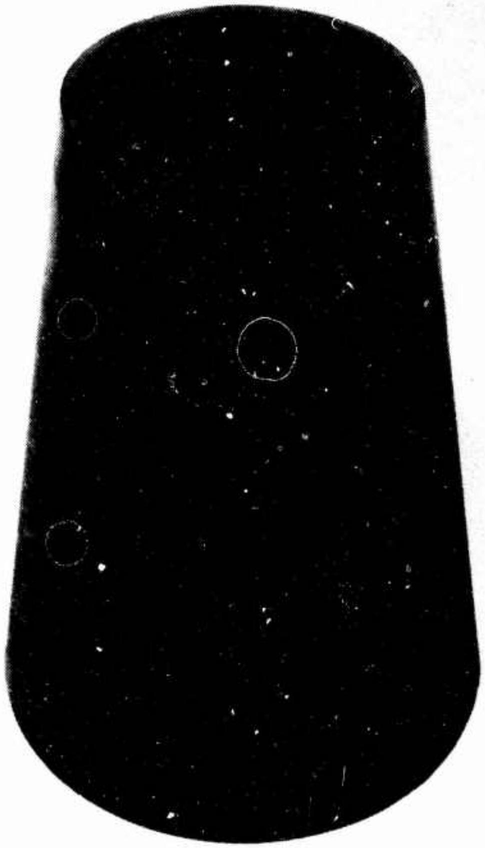


Figure 4-34. Titanium Foil Plies Visible on Outside of Cone

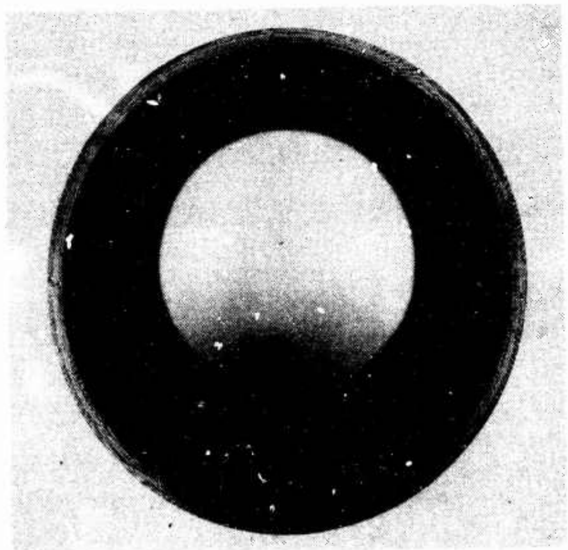


Figure 4-35. Edge View of Repaired Cone

Table 4-11. Summary of Dimensional Data on Cones 1 through 6, Drawing 48126

Dimensions (inches)	Dwg 48126 Requirements	Cone 1	2	3	4	5	6
Base Diameter - Large End	7.79±0.02	7.79	7.774	7.775	7.774	7.77	7.78
Base Diameter - Small End	5.80±0.02	5.80	5.796	5.805	5.805	5.81	5.81
Concentricity of Rings - Both Ends	0.02	*	*	0.020	0.020	*	*
Flatness - Small End	0.005	0.002	0.0005	0.002	0.001	0.003	0.003
Parallelism of Ends	0.010	0.001	0.003	0.003	0.001	0.002	0.002
Flatness - Large End	0.005	0.001	0.002	0.001	0.001	0.001	0.001
Height	9.10±0.03	9.10	9.105	9.089	9.086	9.10	9.11

*Shipped without rings per AMMRC instructions.

Table 4-12. Summary of Cone Wall Thickness Measurements on Cones 1 through 6, Drawing 48126

Cone No.	Measurement Locations		
	One-half Inch From Small Diameter	Center Plane of Cone	One-half Inch From Large Diameter
48126-1	0.188, 0.191, 0.190, 0.189	0.191, 0.190, 0.193, 0.188	0.265, 0.263, 0.272, 0.269, 0.266, 0.277, 0.268
48126-2	0.186, 0.187, 0.187, 0.190	0.188, 0.188, 0.184, 0.189	0.270, 0.273 0.272, 0.280
48126-3	0.183, 0.184, 0.183, 0.184	0.187, 0.187, 0.201, 0.193	0.266, 0.266, 0.268, 0.268
48126-4	0.197, 0.196, 0.199, 0.200	0.203, 0.203 0.203, 0.201	0.275, 0.275, 0.277, 0.276
48126-5	0.192, 0.196, 0.195, 0.195	0.198, 0.198, 0.196, 0.200	0.286, 0.281, 0.289, 0.292
48126-6	0.190, 0.193, 0.192, 0.194	0.197, 0.193, 0.198, 0.197	0.283, 0.298, 0.287, 0.285

plane of the cones, the measurements ranged from 0.184 to 0.203 in. with an average for the 24 measurements of 0.194 in. In the joint area, the spread in measurements was larger, varying from 0.263 to 0.298 in. The average for these 27 measurements is 0.276 in. For the individual cones, the maximum spread at the small end was 0.004 in., at the center plane 0.014 in. (on a single cone, with all other cones having a maximum spread of 0.005 in.), and at the large end 0.013 in. Per AMMRC instructions, cones 5 and 6 were shipped without aluminum rings.

A delamination in the 48126-1 cone occurred at Martin Marietta during the drilling operation, and this was attributed to the previously mentioned problem of having the titanium foil too close to the outer surfaces. This delamination was patched with epoxy adhesive. Cones 48126-1 and -2 were shock tested by Martin Marietta (Reference 1). The -1 cone was tested in the shock machine to the specified levels in 15 runs in increments from low to high levels.

During shock testing, the delamination in the -1 was opened up and extended 0.125 in. after the input shock of 14,000g corresponding to a peak response shock of 27,000g. Another surface crack, two plies deep, was formed at the same shock level. However, these cracks were not considered detrimental to the splice joint integrity. Cone frustum

48126-2 was tested in a similar manner, and a surface crack was detected after the input shock of 9500g corresponding to a peak response of 21,000g. No further damage was found at high shock levels. The two shock tests are considered successful, and results indicate that design 1 of the joint reinforcement would withstand the maximum shock resulting from stage separation pyrotechnic shocks.

Cone 48126-3 was tested under simultaneous loading of shear, bending, axial load, and lateral pressure and failed at 200 percent of design limit load. Failure occured at the top of the smaller end extending at approximately 45 degrees down toward the larger end. The splice joint was still capable of carrying loads, although the holes were elongated due to plastic bearing deformation. Analysis indicates the ultimate bearing stress is reached at 162 percent of design limit load. Cone 48126-4 was tested under a single shear load. The load was applied at 2000-pound increments, and failure occurred at 34,000 pounds. Analysis predicted local interlaminar shear failure at the forward end at 30,000 pounds and joint failure in net section tension at 36,000 pounds. In both the -3 and -4 tests, the joints proved stronger than the basic shell. The joints are capable of plastic deformation and load transfer to the GY-70/934 laminates above the predicted design load level. The 48126-5 and 48126-6 cones where shipped to AMMRC without rings, and have not been tested to data.

Cone frusta specimens 48126-7, -8, and -9 incorporated the Type 3 Joint Design per Drawing 48126. For these cones, 0.0050-inch thick titanium foil was used in the joint area. The titanium was chemically milled from the 0.0075-inch foil used in the first six cones produced per 48126. Chemical milling was accomplished at Chemical Machining Corp., El Segundo, California.

Processing for the -7, -8, and -9 cone specimens was similar to that used for the first six specimens. The outer titanium plies (ply numbers 2 and 37 as described in Figure 4-33) were eliminated to overcome the splitting problem previously described. Gore sizes, ply orientations, wrap angles, etc., are detailed in Figure 4-33. The preplying, precompaction, and cure cycles were identical to that previously described. Preplying was accomplished after layup of ply 5, ply 17, and ply 28. Precompaction was accomplished after layup of ply 11, ply 22, and ply 32. The cones met the dimensional requirements of Drawing 48126 (see Table 4-13) and were shipped to AMMRC to await testing. Cones -8 and -9 were shipped with aluminum rings bonded on the small end while cone 48126-7 was shipped without rings.

Cone frusta specimens 48126-10, -11, and -12 incorporated the Type 2 Joint Design per Drawing 48126. For these cones, 0.0040-inch thick titanium foil was used in the joint area. The 0.0040-inch coiled stock of 6Al-4V titanium alloy was obtained from Teledyne Rodney Metals, Pico Rivera, California. The same hole pattern in the titanium foil used for the previous 48126 cones was chemically milled by Chemical Machining Corp. Again, processing of the -10, -11, and -12 cones was similar to the first nine cones made per Drawing 48126. Details of the gore sizes, ply orientations, wrap angles, etc., are detailed in Figure 4-32. Titanium ply 2 was moved in

Table 4-13. Summary of Dimensional Data on Cones 7 Through 9, Drawing 48126

Dimensions (inches)	Dwg. 48126 Requirements	Cone 7	Cone 8	Cone 9
Base Diameter - Large End	7.79±0.02	7.78	7.77	7.77
Base Diameter - Small End	5.80±0.02	5.81	5.80	5.81
Concentricity of Rings - Small End	0.02	*	<0.02	<0.02
Flatness - Small End	0.005	0.001	0.001	0.001
Parallelism of Ends	0.010	0.001	0.001	0.000
Flatness - Large End	0.005	0.001	0.001	0.002
Height	9.10±0.03	9.12	9.09	9.10

*Shipped without rings per AMMRC instructions.

between the 90 degree and 45 degree plies listed as plies 6 and 7, while titanium ply 57 was moved between the 45 degree and 90 degree plies listed as plies 52 and 53. This eliminated the splitting problem previously encountered on drilling holes in cones 48126-1 and -2. Preplying was accomplished after layup of ply 7, ply 22, ply 37, and ply 52. Precompaction occurred after layup of ply 15, ply 30, and ply 44. Preplying, precompaction, and cure cycles were identical to those used previously on the 48126 cones.

Cone 48126-11 was damaged during machining. This is shown in Figure 4-36. The damage was attributed to an error in machining practice. The normal practice consists of trimming the all graphite/epoxy end of the cone by use of a diamond plated milling cutter run at 3200 rpm while the part is located on a rotary table. The cutting is made without any coolant, and the part is located by hand until the desired depth of cut is achieved. The other end of the cone containing the interleaved titanium foils was machined using a high speed end mill run at 110 rpm. The method of cut is with the periphery of the cutter to ensure constant cutting edge contact with the work material, thus eliminating the delamination problem. Again, no cutting fluid was used.

The damage to the -11 cone was only in the outer two or three plies. It was believed that this cone could be repaired and still meet design requirements. But since this program was essentially a test program, it was decided to remake the -11 cone. There was insufficient 0.0040-inch titanium foil for the new cone so some of the 0.0075-inch foil was chemically milled to 0.0040 inch. The new cone, referred to as -11R, was made identically to the process previously described for -10, -11, and -12 cones. Table 4-14 summarizes dimensional data measured on cones 48126-10, -11R, and -12. The cones were shipped to AMMRC and are awaiting test.

The cones made with Joint Designs 2 and 3 were as uniform in thickness as reported earlier for Joint Design 1. Table 4-15 gives wall thickness measurements on a sampling of cones that were checked for uniformity.

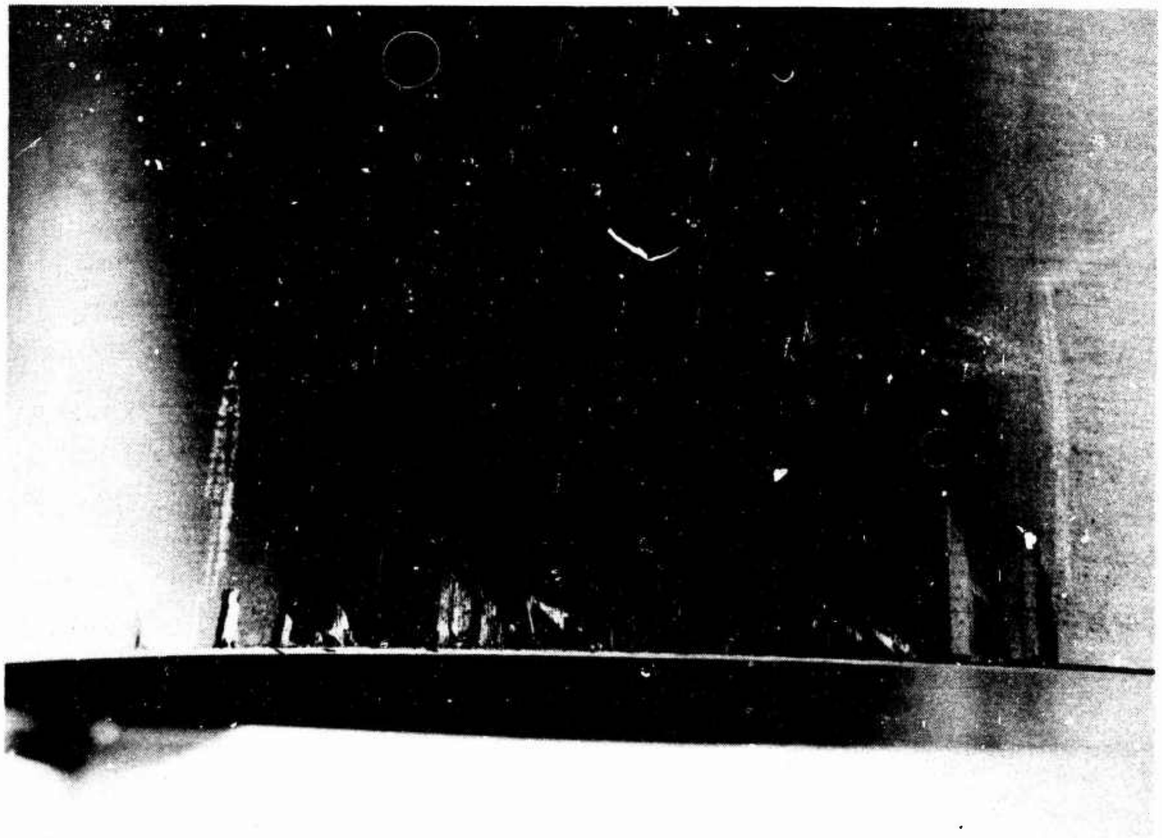


Figure 4-36. Machining Damage of Large Diameter of Cone 48126-11

Table 4-14. Summary of Dimensional Data on Cones 10 Through 12, Drawing 48126

Dimensions (inches)	Dwg. 48126 Requirements	Cone 10	Cone 11R	Cone 12
Base Diameter - Large End	7.79± 0.02	7.80	7.79	7.77
Base Diameter - Small End	5.80± 0.02	5.81	5.81	5.82
Concentricity of Rings - Small End	0.02	<0 02	*	<0.02
Flatness - Small End	0.005	0.003	0.001	0.001
Parallelism of Ends	0.010	0.002	0.001	0.002
Flatness - Large End	0.005	0.002	0.001	0.002
Height	9.10± 0.03	9.10	9.10	9.10

*Shipped without rings per AMMRC instructions.

Table 4-15. Summary of Cone Wall Thickness Measurements on Cones 7, 8, and 10, Drawing 48126

	Measurement Locations		
Cone No.	One-half Inch From Small Diameter	Center Plane of Cone	One-half Inch From Large Diameter
48126-7	0.196, 0.197, 0.198, 0.197	0.197, 0.199, 0.200, 0.198	0.199, 0.196, 0.199, 0.195
48126-8	0.196, 0.197, 0.198, 0.196	0.199, 0.199, 0.200, 0.198	0.195, 0.192, 0.192, 0.193
48126-10	0.192, 0.192, 0.192, 0.193	0.196, 0.194, 0.193, 0.193	0.288, 0.286, 0.287, 0.286

Many of the cone specimens in this program were fabricated from prepreg that had been stored at 0F for periods greater than the 180 days specified in ANA74700314-001B (Appendix A). To evaluate the effect of long term storage at 0F on prepreg and laminate properties, three rolls of prepreg having been stored for up to 15 months were selected at random and tested. The results are summarized in Tables 4-16 and 4-17. The results show that the Fiberite HY-E-1534 (GY-70/934) prepreg still meets the requirements of ANA74700314-001B after 15 months storage at 0F. This is confirmed by the excellent test results on the cone specimens and the retention of the same thickness per cured ply characteristics on all of the cones regardless of the prepreg age.

Table 4-16. Effect of Storage History on Prepreg Properties of GY-70/934

Lot/Roll No.	Date of Manufacture	Date of Testing	Volatiles (%)	Resin Solids (Wt %)	Resin Flow (Wt %)	Tack	Drape
4E-20/R6	10-17-75	2-7-77	0.68	39.86	20.24	Pass	Pass
			0.63	41.26	24.44	Pass	Pass
			0.74	40.82	24.19	Pass	Pass
			Avg 0.69	40.65	22.95	Pass	Pass
Initial Fiberite QC Data			0.7	39.9	21.7		
4E-31/R-2	11-6-75	2-7-77	0.71	40.36	18.15	Pass	Pass
			0.75	38.72	16.03	Pass	Pass
			0.81	38.13	19.92	Pass	Pass
			Avg 0.76	39.07	18.72	Pass	Pass
Initial Fiberite QC Data			0.7	38.3	16.0		
4E-31/R-35	11-28-75	2-7-77	0.56	37.87	13.47	Pass	Pass
			0.57	37.89	17.97	Pass	Pass
			0.65	37.77	16.60	Pass	Pass
			Avg 0.59	37.84	16.01	Pass	Pass
Initial Fiberite QC Data			0.5	41.1	19.9		

Table 4-17. Laminate Flexure Data on Composites Made From GY-70/934 After Long Term Storage at 0F

Prepreg Lot/Roll No.	Date of Manufacture	Date of Panel Fabrication	Flexure Strength (ksi)	Average Cured Resin Content (Wt %)	Average Fiber (Volume %)
4E-20/R6	10-17-75	2-7-77	120		
			128		
			135		
			Avg 128	26.49	64.80
4E-31/R2	11-6-75	2-7-77	111		
			119		
			112		
			Avg 114	28.51	62.45
4E-31/R35	11-28-75	2-7-77	129		
			135		
			137		
			Avg 134	28.07	62.90

SECTION 5

CONCLUSIONS

1. A manufacturing process was demonstrated for manufacturing cone frusta specimens from ultra-high-modulus graphite/epoxy (GY-70/934) prepreg using female bulk graphite tools and gore sections of prepreg. These cone specimens were successfully tested by Martin Marietta, and the results generally met or exceeded analytical predictions.

2. A manufacturing process was developed and demonstrated for incorporating titanium foils between layers of graphite/epoxy prepreg. Cone frusta specimens with varying joint designs of interleaved titanium foils were successfully built. Again, testing of these specimens by Martin Marietta met or exceeded analytical predictions.

3. Perforations in the titanium foils allowed resin bleeding and escape of volatiles. This resulted in cone frusta joint specimens having predictable, uniform wall thicknesses.

4. Fiberite HY-E-1534 (GY-70/934), ultra-high-modulus graphite/epoxy prepreg was qualified to Martin Marietta Material Specification ANA74700314-001B.

5. The GY-70/934 prepreg was demonstrated to have a shelf life at 0F exceeding 15 months.

SECTION 6

RECOMMENDATIONS

1. Complete testing of conical frusta joint specimens and determine most efficient joint that will survive structural requirements of advanced ABM.

2. Design, build, and test specimens representing conical sections with bulkheads and/or ring stiffeners, cut-outs, antenna windows, etc. out of graphite/epoxy composite.

3. Build and test a full-scale, advanced ABM guidance and control section out of graphite/epoxy composite.

4. Evaluate environmental effects pertinent to advanced ABM. This may include moisture, permeability, nuclear hardness, electrical conductivity, etc.

REFERENCES

1. Koo, F.H. and Seinberg, J.P., "Subscale Development of Advanced ABM Graphite/Epoxy Composite Structure," Martin Marietta Corp., Report AMMRC TR 78-4, U.S. Army Materials and Mechanics Research Center Contract No. DAAG46-75-C-0097, Final Report, January 1978.

APPENDIX A

GRAPHITE/EPOXY PREPREG SPECIFICATION

(Martin Marietta ANA74700314-001B)

1.0 SCOPE

1.1 Requirements

This specification establishes requirements for staged, impregnated, fibrous graphite materials in the following forms:

(1) yarns or tows
(2) multifilament collimated yarns or tows
(3) woven fabric
(4) chopped mat

1.2 Classification

1.2.1 Types. The graphite fibers are of high quality and are available in the following types:

Type I : High Modulus Fibers, surface treated.
Type II : High Tensile Strength Fibers, surface treated.
Type III: Intermediate Tensile Strength Fibers, surface treated.
Type IV : Ultra High Modulus Fibers made from single or double yarns, surface treated.
Type V : Ultra High Modulus Fibers in the form of a tape constructed from collimated yarns or tows, surface treated.

1.2.2 Class. The various types of graphite shall be supplied in the following forms or classes:

Class 1 - Continuous yarns, typically with 1/2 twist per foot and having up to 4000 filaments per yarn.
Class 2 - Continuous yarns, untwisted or twisted, having up to 4000 filaments per yarn.
Class 3 - Continuous tows, untwisted or twisted, consisting of more than 4000 filaments. Tows typically have between 10,000-150,000 filaments.
Class 4 - Continuous dry flat tape, typically three inches wide, consisting of 100-200 yarns per inch width.
Class 5 - Chopped Mat made from Class 1, 2, 3, or 4. Cut typically to one inch lengths and randomly oriented.
Class 6 - Fabrics woven to commercial standard forms from Class 1, 2, 3 or 4 fibers.

1.2.3 Resin Grades. Various grades of resin can be employed. If no Grade is specified, Grade A shall be supplied.

Grade A - An epoxy resin, typically but not limited to an amine catalized system, free of foreign materials, non-corrosive to metals and shall be capable of being molded at pressures of 110 pounds per square inch (psi) maximum to a fully thermoset state meeting the cured laminate properties of this specification.

1.3 Application. The impregnated material covered in this specification is intended for use as primary and secondary structure in aerospace systems.

NOTE: The commercial designation for both fiber and resin shall be specified on the purchase order.

2.0 APPLICABLE DOCUMENTS

The following documents of the issue in effect on date of invitation for bids or requests form a part of this specification to the extent specified herein.

MIL-R-9300	Resin Epoxy, Low-Pressure Laminating
ASTM-D-696	Coefficient of Linear Expansion of Plastics
ASTM-D-2702	Determination of the Infrared Absorption Characteristics of Rubber Chemicals
AMS-3894	Graphite Fiber Tape and Sheet

3.0 REQUIREMENTS

3.1 Fibers

3.1.1 Fiber Types. The classification types as noted in Section 1.2 shall be employed. When a specific product is needed, a commercial fiber meeting the requirements of type and class as noted in Sections 1.2.1, 1.2.2 will be specified by name on the purchase order.

3.1.2 Surface Treatment. All fibers shall have a active surface treatment or sizing which will be compatible with the resin system employed. The prepreg certification document shall contain the process identification number, as specified by the Fiber Manufacturer, for the sizing or surface treatment employed. If no such number is available, then a statement by the prepreger insuring Martin Marietta Aerospace that a compatible surface treatment has been used on the fiber is required.

3.1.3 Mechanical Properties. Nominal and minimum acceptable modulus, strength, and density properties of the fiber types are given in Table I. It will be the responsibility of the prepreg supplier to ascertain that the fiber properties fall within the prescribed limits. The prepreg delivery document shall contain the fiber property certification for the fiber lot used in the preparation of the prepreg.

3.1.4 Workmanship. The graphite material shall be suitable for production of a high quality finished product, and as such, shall not contain any evidence of foreign matter, fiber deterioration, discontinuity, loops, entrapped ends, fuzz balls, or excessive sizing which could cause adherence of adjacent strands and breaking during an unwinding process.

3.1.5 Handling. Normal handling of the graphite tow, yarn or tape shall not degrade the mechanical properties. Material will be stored on spools having a diameter of not less than three inches.

3.2 Resin

3.2.1 Quality. The resin system to be used for the prepreg material specified herein shall be of high quality and entirely suitable for impregnation of surface treated graphite yarns, tows, and tape.

3.2.2 Properties. The resin system employed shall be of a quality to meet the specified requirements of this document. It shall meet the general requirements of MIL-R-9300, in particular paragraphs 3.2, 3.3, 3.4, 3.5, 3.8, and 3.9.

3.2.3 Designation. The specific vendor resin system designation will be specified on the procurement document.

3.2.4 Formulation Change. A letter of specification compliance shall be required with each prepreg shipment. Such a document will guarantee that no resin formulation changes have occurred since the time of qualification.

3.3 Prepreg - Uncured

3.3.1 Prepreg forms. Graphite tows, yarns, woven fabrics and tapes, when impregnated with a resin system as described above, shall constitute a prepreg system. Several forms of prepreg systems are described as follows:

3.3.1.1 Prepreg Yarn. Single yarns or tows, resin preimpregnated, and partially staged and packaged in single, non-contacting layers on a 12 inch long by 3 inch diameter spool (approximate).

3.3.1.2 Prepreg Unidirectional Tape. Multiple single yarns or tows collimated into wide flat dry tapes of continuous parallel fibers. These are then resin preimpregnated, partially staged, and packaged in level wound roll form. Tape width may vary from 1/4 inch to 24 inches. Standard width is 3 inches. The package roll shall have a minimum radius of 3 inches.

3.3.1.3 Woven Fabric. Suitable graphite yarns and tows are cross woven to a specified pattern on mill equipment. The fabric is treated, resin preimpregnated and staged. Prepreg size shall be continuous in the warp direction and not less than 24 inches in the fill direction. The fabric shall be produced and packaged in accordance with the applicable purchase order.

3.3.1.4 Chopped Mat. Suitable graphite yarns or tows shall be chopped to a specified length, usually 1/2 to 1 inch, and immersed in a wide flat sheet of resin. The fiber orientation shall be random so as to generate isotropic properites in the plane of the sheet. After staging, the mat shall be packaged in accordance with the applicable purchase order.

3.3.2 Prepreg Properties

3.3.2.1 Physical Properties. The Grade A resin prepreg material shall meet the physical property requirements set forth in Table II. The tests shall be performed on prepreg material which is stored at 0°F for not less than 16 hours and returned to ambient temperature.

3.3.2.2 Prepreg Cosmetics

3.3.2.2.1 General Requirements. The prepreg materials should be well aligned, of constant thickness, and free of foreign materials, resin rich or resin starved areas, yarn or tow crossovers, knots, wrinkles, and an excessive number of splices and gaps. If, within a given roll of material, there are areas not conforming to this specification, they will be properly noted by flagging with a colored tag.

3.3.2.2.2 Alignment

(1) Tape: Alignment of the collimated tow or yarn within the impregnated tape shall not deviate more than .020 inches in any one linear foot. Areas not conforming to this criteria shall be flagged.

(2) Single yarn/tow: All fibers within the yarn or tow shall remain in close proximity to one another. No kinking, curling, or knotting of the fiber bundle will be permitted. Variations in wetted fiber bundle diameter greater than one half the mean diameter are cause for rejection. Non-conforming areas shall be flagged.

(3) Woven Fabric: The alignment of the warp and fill yarns of the fabric shall be perpendicular to each other and shall be parallel in the warp and fill direction of the impregnated fabric within a two inch span of the full cloth width exclusive of selvage, or 42 inch length, but not more than 1 inch in any 21 inches of cloth width or length. Areas not conforming to this criteria shall be flagged.

(4) Chopped Mat: A completely random orientation is required so as to generate isotropic properties in the plane of the mat.

3.3.2.2.3 Width

(1) Tape: Material shall be supplied in widths specified on the purchase document. Tape width tolerance shall be ±0.1 inch for nominal widths of 1 to 12 inches inclusive.

(2) Single yarn/tow: To be specified on the purchase document.

(3) Woven Fabric: The impregnated fabric width shall remain within a tolerance of plus or minus one inch of the specified purchase order width. The specified width shall be exclusive of the selvage areas of the impregnated material.

(4) Chopped Mat: Chopped mat supplied to this specification shall remain within plus or minus one-half inch of the dimensions described in the applicable purchase order.

3.3.2.2.4 Gaps

(1) Tape: Continuous gaps between adjacent tows or yanrs not exceeding 0.10 inch are acceptable provided that no more than three of these gaps occur simultaneously over any three inch width. Continuous gaps between adjacent tows or yarns shall not exceed .1 inches in width by six inches in length and shall not be more than eight feet accumulative total length for each hundred feet of length. Gaps in excess of this criteria shall be flagged as non-conforming areas and shall not be included in the net weight of the roll of material.

(2) Single Yarn/tow: No visually observable gaps are acceptable. Spools having more than ten gaps per 100 feet of prepreged yarn/tow are acceptable provided the 100 foot sections are flagged. These sections shall not be included in the net spool weight.

(3) Woven Fabric: Continuous gaps between parallel tows or yarns not exceeding 0.025 inch are acceptable in both warp and fill directions. Gaps up to 1/8 inch wide by 2 inches long between parallel fibers (warp or fill) are acceptable so long as no more than five such gaps appear in any foot square section of fabric. An entire fabric sheet (2 feet by 5 feet, or greater) shall be rejected if more than forty 1/8 inch wide gaps are present.

(4) Chopped Mat: An entire mat sheet (2 feet by 5 feet, or greater) shall be rejected if more than forty 3/16 inch diameter gaps (holes) are visible in the sheet.

3.3.2.2.5 Splices

(1) Tape: Splices of individual parallel yarns/tows are permitted so long as no two occur within 1/2 inch of each other. No splices shall be permitted across the width of the tape.

(2) Single yarn/tow: Splices in the prepreged yarn/tow roving are permitted providing the splice length is 1 to 2 inches, and no more than one splice occurs in any 100 foot section.

(3) Woven Fabric: Anomolies in the cosmetic appearance of the woven fabric which are a result of splices in the yarn controlled by the yarn specification or revisions thereof shall be identified by a colored marker in the selvage area of the woven fabric. The presence of these anomolies shall not be considered as non-conforming areas.

3.3.2.2.6 Flatness

(1) Tape: The prepreg tape shall adhere uniformly to the carrier material and shall not wave out of plane from the carrier. Areas not adhering to the carrier or exhibiting an out of plane wave greater than .02 inch will be flagged.

(2) Woven Fabric: Fabric sheets shall, when unrestrained, lay flat within ± 1/4 inch. A 1/2 inch border around the sheet will be exempt from this requirement.

(3) Fiber Mat: Same as (2), Woven Fabric.

3.3.2.2.7 Flash

(1) Tape: Resin flash shall not extend 1/16 inch beyond the edge of the tape.

(2) Single yarn/tow: Resin flash shall not extend 1/64 inch beyond the edge of the tow/yarn.

3.3.2.2.8 Material Uniformity. Prepreg areas shall be flagged for any of the following reasons:

(1) Tow/yarn crossovers and knots.

(2) Material wrinkles (marcelling) greater in amplitude than ± 1/64 inch and not covered by the alignment requirement.

(3) "Fuzzballs" which adhere to the prepreg tape or fabric and which cannot be removed with a pick or tweezers without damaging underlying fibers.

(4) Puckering due to excessive or uneven tension on the separator film.

(5) Appearance of foreign matter of any observable form on the prepreg, to include dirt particles, fingerprints, moisture, etc., and films such as oil, glazing, lacquer, etc.

(6) Incomplete splices, fish eyes, resin rich or resin starved areas, gaps, or buckles or other anomalies associated with material non-uniformity.

3.3.3 Prepreg Carrier

3.3.3.1 Tape Carrier. A thin paper, plastic, or equivalent carrier tape, at least as wide as the prepreg shall be used for backing material. It will be light colored so as to contrast to the black graphite prepreg and will be coated with a fully cured non-transferring release agent. The prepreg will adhere to the paper tape but be easily removable at ambient conditions by manufacturing personnel. Also, the prepreg-carrier combination will be easily cut with an ordinary paper cutting device.

3.3.3. Single yarn/tow Carrier. The same paper carrier described above in 3.3.3.1 will be used. The carrier here, however, will serve only to separate successive layers of single yarn/tow on the spool, as described in Section 3.3.1.2.

3.3.3.3 Woven Fabric Carrier. The same paper carrier used in 3.3.3.1 is acceptable here. No requirement exists, however, that the fabric stick to the carrier. The carrier will extend at least 1 inch beyond the specified purchase order width.

3.3.4 Prepreg Handling Characteristics

The prepreg material, when handled by experienced manufacturing personnel, will not tear, shred, fray, or become otherwise damaged. The material shall maintain tack and drape as tested by 4.10.3.5 and 4.10.3.6 for the duration of its working life.

3.3.5 Prepreg Storage

3.3.5.1 Shelf Life. The prepreg material shall meet the requirements of this specification when stored for 180 days at 0°F or 270 days at -65°F. Storage time commences on date of receipt.

3.3.5.2 Working Life. The prepreg material shall meet all requirements of this specification after exposure (either continuous or accumulative) from 65° to 85°F for 10 days while stored in a sealed, moisture proof plastic bag. If not bag sealed, the prepreg shall still meet all requirements of this specification after room exposure (85°F, 75 percent humidity maximum conditions) for 72 continuous or accumulative hours.

3.4 Prepreg - Cured Laminate

3.4.1 Test Laminate Fabrication

Cured laminate properties shall be determined from specimens prepared in accordance with Section 4.9.1.

3.4.2.1 Fiber-Resin-Void Content of cured laminates shall be measured as per 4.10.4.2 or an approved vendor process and shall conform to the limitations in Table III.

3.4.2.2 Laminate Thickness shall be measured as per 4.10.4.3 and shall conform to the limitations in Table III.

3.4.2.3 Composite Density shall be measured in accordance with Section 4.10.4.1.

3.4.2.4 Thermal Coefficient of Expansion in the longitudinal and transverse directions will be measured in accordance with ASTM D-696 (Coefficient of Linear Thermal Expansion of Plastic) or equivalent.

3.4.3 Mechanical Properties

3.4.3.1 Specimen Geometry. Tape, fabric, yarn, and chopped mat materials shall utilize flat geometries for acceptance and qualification tests. The vendor shall certify that the prepreg yarn/tow, if formed into wide tape could be laminated into unidirectional specimens having the properties of Table IV.

3.4.3.2 Thermal Requirements. Specimens shall be mechanically tested at room temperature and 350°F. The number of required tests at temperature is provided in Table IV. Thermal expansion coefficients will also be measured at room temperature and 350°F.

3.4.3.3 Modulus/Strength Requirements

3.4.3.3.1 Tape. The mechanical properties of unidirectional composites fabricated from Grade A resin prepreg tapes shall meet the requirements of Table IV. All strength and modulus test data shall be normalized for 63 percent fiber volume as described in Section 3.4.3.4. Laminates under test must meet the physical property limits set forth in Table III.

3.4.3.3.2 Yarns/Tows. The tensile modulus and strength of laminated composites fabricated from yarns/tows into rings shall conform to the appropriate fiber value of Table IV. Values shall be normalized as necessary.

3.4.3.3.3 Fabric. The following mechanical properties for woven fabric shall be specified on the purchase document:

(1) Warp and fill tensile strengths.

(2) Warp and fill tensile moduli.

(3) Warp and fill flexural strengths.

(4) Warp and fill flexural moduli.

(5) Warp and fill short beam (interlaminar) shear.

(6) Allowable coefficients of variation.

The above properties (both minimum and average values) shall be specified at room temperature and 350°F. The appropriate tests shall be conducted to insure conformance with these specified properties.

3.4.3.3.4 Chopped Mat. The following isotropic mechanical properties (both minimum and average values) shall be specified on the purchase document:

(1) Tensile strength
(2) Tensile modulus
(3) Flexure strength
(4) Flexure modulus
(5) Allowable coefficients of variation

The above properties shall be specified at room temperature and 350°F. The appropriate tests shall be conducted to insure conformance with these specified properties.

3.5 Normalized Properties.

All longitudinal tensile and longitudinal flexure mechanical property requirements shown in Table IV are based on a 63 percent fiber volume. Normalize mechanical data by using the correction factor (AFV/63) as follows:

$$\sigma_c = \sigma_{test} \cdot \left(\frac{63}{AFV}\right)$$

$$E_c = E_{test} \cdot \left(\frac{63}{AFV}\right)$$

where AFV is the actual fiber volume, percent, as determined by 4.10.4.2, σ_{test} and E_{test} are the test data as determined by 4.10.4.5, 6, 7, and σ_c and E_c are the corrected values.

3.6 Statistical Reduction of Data

The coefficient of variation for all composite mechanical test data shall be computed as follows:

Mean value $\bar{X} = \dfrac{\sum_{i=1}^{N} X_i}{N}$

Standard deviation $\sigma = \sqrt{\dfrac{\sum_{i=1}^{N} (\bar{X} - X_i)^2}{N - 1}}$

Coefficient of variation $V = \dfrac{\sigma}{\bar{X}} \times 100$

where X_i are the test data and N is the test population.

The maximum allowable coefficients of variation are given in Table IV. Material lots not meeting this requirement shall be rejected. A retest for any and all mechanical properties failing to meet this variational requirement shall be permitted, so long as the minimum and average values of Table IV have been met. This paragraph takes specific exception to Section 4.7.

4.0 QUALITY ASSURANCE PROVISIONS

4.1 Qualification Tests

Unless otherwise specified in the contract or purchase order, the supplier is responsible for the performance of all requirements as specified herein. Except as otherwise specified, the supplier may utilize his own facilities or any commercial laboratory acceptable to the procuring activity. The procuring activity reserves the right to perform any of the inspections set forth in the specification where such inspections are deemed necessary to assure supplies and services conform to prescribed requirements. Table V (a) is a list of the mechanical and physical tests required for qualification of a material system. The vendor shall be required to perform all tests unless other wise specified. Table VI and Table VII show the number and type of specimen required.

4.2 Acceptance Tests

Acceptance tests are those tests required for each shipment or lot of material to insure the quality of the product. Acceptance tests shall consist of those listed in Table V (b).

The specific number of tests for the various properties and the required test temperatures are shown in Table VI. The minimum number of panels required to obtain the correct number of specimens are listed in Table VII.

4.3 Test Reports

Complete test inspection records shall be maintained by the prepreg supplier. Test reports as required by this specification shall be prepared and delivered to Martin Marietta Aerospace at the time of material delivery.

4.4 Sampling Units

4.4.1 Lot. A lot is the prepreg material produced in one manufacturing run under relative uniform conditions. Lot numbers will be specified by the prepreg supplier.

4.4.2 Unit. One roll of continuous tape, yarn, or fabric or a maximum of 10 pounds of sheet material.

4.5 Qualification/Acceptance

4.5.1 Qualified Vendor. A vendor will be qualified for a material system when all requirements of this specification are met and vendor test data is supplied to and verified by Martin Marietta Aerospace. A qualification test report detailing the test results as required by Table V shall be delivered to Martin Marietta Aerospace.

4.5.2 Acceptance. Qualified vendors shall be required to complete all acceptance test requirements listed in Table V. An acceptance test report shall be delivered to the purchasing agency, including unimpregnated material data described in Tables I and V.

4.5.3 Certification. The prepreg vendor shall certify that each delivery meets all requirements of this specification.

4.5.4 Formulation and Process Change. A vendor cannot change the materials or fabrication process of a qualified product without prior notification to and approval of Martin Marietta Aerospace. Such changes may require requalification.

4.5.5 Witness. Martin Marietta Aerospace reserves the right to witness any and all testing conducted by or for the prepreg vendor.

4.6 Cause for Rejection

4.6.1 Prepreg. Defective areas of preimpregnated tapes, yarns/tows, fabrics, and mats not conforming to the requirements of 3.3.2.2 (cosmetics) shall be flagged as non-conforming areas and shall not be included in the net weight of a given material type. Prepreg units shall also be rejected for nonconformance as specified in 3.3.4 (handling). Remaining portions of an acceptable lot shall be rejectable for nonconformance to 3.3.5 (storage life).

4.6.2 Cured Laminates. The entire material lot shall be rejected for nonconformance with 3.4.3.3 (modulus and strength requirements).

4.7 Retest

Should a material lot fail to meet one or two acceptance or qualification requirements, a retest of the failed properties is permitted. The material lot shall be acceptable if the requirements are met on the retest. A second retest is not permitted.

4.8 Recertification

Martin Marietta Aerospace reserves the right to require recertification of any vendor.

4.9 Fabrication of Test Specimens

4.9.1 Flat Panels. The actual cure cycle and laminate fabrication procedure will be selected by the prepreg vendor. After flat panels have been fabricated, actual test specimens will be prepared in accordance with AMS 3894, except as noted in Section 4.10.4. Tensile, flexure and short beam shear specimens shall be cut from the completed test panels. Also, the panels should be made sufficiently large so that the specimens needed for thermal expansion and fiber-resin-void determination may be obtained.

An optional layup procedure is shown in Figure 1. For Grade A resins, the pressure-temperature cure cycle should consist of an initial heat up to 250°F (6° - 10°F/min) under vacuum bag pressure (14 psi), application of 50-100 psi autoclave pressure and optional venting of vacuum bag, heat up to 350°F, dwell for 1-2 hours, cool down under pressure, and final release of pressure. Any significant deviations from this process shall be noted. The prepreg vendor shall specify the cure cycle on the test report.

NOTE: For Grade A resins only, cure pressures in excess of 125 psi or cure temperatures in excess of 400°F are unacceptable.

4.10 Test Procedures

4.10.1 Fiber Tests. Any tests required by the prepreg vendor on the fiber shall be specified by the prepreg vendor. Results of such tests will be reported to Martin Marietta Aerospace.

4.10.2 Resin Tests. The extent and type of tests performed on each batch of resin formulation prior to and during the impregnation process shall be at the discretion of the prepreg vendor. Results of such tests will be reported to Martin Marietta Aerospace, provided that the disclosure of such test results will not, in the opinion of the prepreger, compromise a proprietary formulation. A statement on the prepreg certification as to the type resin employed is required.

4.10.3 Uncured Prepreg Tests

4.10.3.1 Nonfiber content. Nonfiber content, percent by weight of the uncured prepreg, shall be determined by either an approved vendor substitute process or per AMS 3894 with the following differences:

(1) Demethylformamide or methylene chloride shall be employed as the solvent.

(2) Use a minimum of 100 ml fresh solvent for each washing.

(3) In place of solvent boiling soak, the uncured prepreg samples can be solvent extracted using a Soxhlet Extraction apparatus, recycling the solvent at least 4 to 10 times every hour for a minimum of 6 hours.

(4) All samples are to be weighed within 20 seconds after removal from dissicator.

4.10.3.2 Resin Flow. Resin Flow, percent by weight of the uncured prepreg, shall be determined by either an approved vendor substitute process or per AMS 3894 with the following differences:

(1) Platen to be preheated to 325° ± 5°F.

(2) Apply 50 ± 3 psi.

(3) Bleeder cloth shall be 120 or 181 style fiberglass, or equivalent.

(4) Release cloth may be EMFAB TX1040 or equivalent.

4.10.3.3 Volatiles. Volatile content, percent by weight of the uncured prepreg, shall be determined by either an approved vendor substitute process or per AMS 3894 with the following differences:

(1) Tests to be conducted at 325° ± 5°F.

(2) Heat samples for 15 to 16 minutes.

(3) Volatile tests at temperatures and times recommended by the vendor, if different from this specification, will also be conducted and reported.

(4) Specimen shall be suspended by alligator clip or equivalent.

4.10.3.4 Gelation. Resin gel time shall be determined by either an approved vendor substitute process or per AMS 3894 with the following differences:

(1) Repeat gel test at 3 different temperatures, 180°, 250°, 350F for qualification tests (test at 350°F only for acceptance tests).

(2) Plot on semilog paper, gel time on logarithmic axis.

(3) Reaction rate, C, shall be determined as follows:

$$C = \frac{\log \theta_1 - \log \theta_2}{[\log e]\,[T_1 - T_2]}$$

where θ_1 = gel time at lower temperature T_1

θ_2 = gel time at higher temperature T_2

T_1 = lower temperature taken from straight line plot

T_2 = higher temperature taken from straight line plot

$\log e = 0.434$

NOTE: The material lot shall be rejected if the gel time at 350°F exceeds (To be determined) minutes.

4.10.3.5 Tack. Prepreg tack shall be determined by either an approved vendo substitute process or per AMS 3894 with the following differences:

(1) Clean smooth glass surface may also be used as a test panel.

(2) When touched lightly with clean hands, the resin will not transfer from the prepreg to the fingers at 70 to 75°F.

4.10.3.6 Drape. Prepreg drape shall be reported as "pass" or "fail."

4.10.3.6.1 For unidirectional staged prepreg tape, cut three 2 inch long by 3 inch wide samples. Each specimen will be bent 90° over a 1/8 inch radius clean metal surface at room temperature (70°-77°F). The bend will be made parallel to the fiber orientation and the sample will be pressed against the metal surface with light contact pressure. To pass the drapability test, the specimens shall adhere to the metal surface for 10 minutes without springback, and no fiber damage shall be visible under 10x magnification. All three tests must pass to meet the drapability requirement.

4.10.3.6.2 For fabric prepreg, six 3 inch square specimens will be used. The drape test will be conducted as in 4.10.3.6.1 for both warp and fill directions. All six tests must pass to meet drapability requirements.

4.10.3.6.3 An approved vendor substitute process may be used for the drape test.

4.10.3.6.4 Material exposed to ambient conditions for more than 24 hours (unsealed) shall not be subjected to the drape test.

4.10.3.7 Staging. Prepreg material, when delivered to Martin Marietta Aerospace, shall be staged. The degree of staging, as well as the required test procedures to determine same, may be specified on the purchase document.

4.10.3.8 Infrared Spectrograph. An infrared spectrograph of the staged resin shall be supplied at the time of certification. The procedure employed to extract the staged resin from the prepreg, including solvents employed, method of solvent removal and type of infrared cells employed shall be reported. Procedures outlined in ASTM D2702 shall be followed.

4.10.4 Cured Prepreg (Laminate) Tests

4.10.4.1 Density. The density of a test laminate shall be determined in accordance with ASTM D792.

4.10.4.2 Fiber/Resin/Void Content. Using specimens from the same test laminates prepared for mechanical testing, the laminate fiber/resin/void content shall be determine using either an approved vendor substitute method or a nitric acid digestion technique outlined in AMS 3894 with the following differences;

(1) Stabilize the temperature of the nitric acid using a boiling water bath at 212°F.

(2) The sample to be tested will be in one piece of at least 3 grams.

(3) Digest the sample in the hot nitric acid for 90 - 100 minutes, stirring continuously with a magnetic stirrer or once every 10 minutes with a glass rod.

(4) Cool the sample 30 minutes.

(5) Filter with an all glass filter apparatus, using vacuum assist, with Millipore Corporation's (Bedford, Massachusetts) LCWP04700 Filters, or equivalent.

(6) Rinse the fibers in the filter as follows:

Twice with 100 ml each HNO_3

Twice with 100 ml each distilled water

Twice with 100 ml each acetone

When rinsing, stop vacuum, add the liquid, stir, then apply vacuum. Remove the liquid from the Buchner funnel when changing type of rinse.

(7) Dry the carbon fibers in a vacuum oven set at 212° ± 5°F @ 29 inches mercury vacuum for one hour minimum.

(8) Cool in desiccator.

(9) Weigh within 20 seconds of removal from desiccator.

Computations are as follows:

% Fiber (weight) $\left(\frac{W_f}{W_L}\right) \times 100$

% Resin (weight) $\left(\frac{W_L - W_f}{W_L}\right) \times 100$

% Fiber (volume)=FV = $\left(\frac{W_f}{W_L}\right)\left(\frac{\rho_L}{\rho_f}\right) \times 100$

% Resin (volume)=RV = $\left(\frac{W_R}{W_L}\right)\left(\frac{\rho_L}{\rho_R}\right) \times 100$

% Void (volume)=VV = 100 - FV - RV

where

W_L = weight (grams) of laminate before digestion

W_f = weight (grams) of fiber after digestion

ρ_L = density (g/cc) of laminate before digestion

ρ_f = density (g/cc) of fiber as determined by prepreg vendor in 4.10.1.

ρ_R = density (g/cc) of resin as determined by prepreg vendor in 4.10.2.

Three separate acid digestion tests will be conducted on the test laminate. Results of all three tests will be reported.

4.10.4.3 Laminate Thickness. The laminate used to determine ply thickness shall be of the $[0/90/0/90]_{sym}$ type. Laminate thickness shall be measured using a suitable micrometer having ball contact heads. A minimum of 10 evenly spaced readings shall be made, all being at least 1/2 inch from any edge. Laminate thickness shall be the average of 10 readings. Average ply thickness will be reported as

$$t/\text{ply} = \frac{\text{thickness of laminate}}{\text{total number of plies}}.$$

4.10.4.4 Tensile Strength, Modulus

4.10.4.4.1 Flat Specimens. Longitudinal and transverse tensile specimens shall be tested in tension and modulus and strength data shall be determined in accordance with AMS-3894 with the following noted exceptions.

(1) Crosshead speed shall be 0.050 inches/minutes.

(2) Five fabric specimens in the fill direction shall be tested at room temperature and five fabric specimens in the fill direction shall be tested at 350° ± 5°.

(3) Five fabric specimens in the warp direction shall be tested at room temperature and five fabric specimens in the warp direction shall be tested at 350° ± 5°.

(4) Five longitudinal tape specimens shall be tested at room temperature and five shall be tested at 350° ± 5°. Five transverse tape specimens shall be tested at room temperature.

(5) For measuring fabric specimen dimensions, a micrometer with one flat anvil and 0.200 inch diameter ball shall be used. A ball micrometer shall be used for tape specimens.

(6) Procedural testing shall be in accordance with specification AMS-3894 except that specimen length shall be 9.0 inches, and width shall be .50 inches.

(7) Calculation of modulus of elasticity for room temperature specimens shall require the use of an extensometer or strain gages and elevated temperature testing shall employ the use of strain gages.

(8) For 350° ± 5°F. testing: The thermocouple shall be positioned within one-half inch of each specimen to be tested and testing shall be conducted after 10 ± 1 minutes exposure to the specified temperature requirement.

(9) Longitudinal tensile strength and modulus values shall be normalized to 63 percent fiber volume.

(10) Five tests are required for the modulus/strength value. Report the average and the individual test data. Compute and report normalized values and coefficient of variation in accordance with Sections 3.5, 3.6.

4.10.4.5 Flexure Strength/Modulus. Longitudinal and transverse specimens shall be tested in flexure and flexural strength and modulus data shall be determined in accordance with AMS-3894 with the following exceptions.

(1) Crosshead speed shall be 0.050 inches/minute.

(2) Five fabric specimens in the fill direction shall be tested at room temperature and five fabric specimens in the fill direction shall be tested at 350° ± 5°F.

(3) Five longitudinal tape specimens shall be tested at room temperature and five at 350° ± 5°F. Five transverse tape specimens shall be tested at room temperature and five at 350°F ± 5°F.

(4) Procedural testing shall be in accordance with AMS-3894. Either three point or four point loading may be used. The method shall be specified on the test report.

(5) Longitudinal strength and modulus values shall be normalized to 63 percent fiber volume.

(6) The thermocouple shall be positioned within 1/2 inch of each specimen to be tested at 350° ± 5°F.

(7) An optional method of computing the flexural modulus will utilize the crosshead motion corresponding to the 1/4 span deflection, in which case

$$E_f = \frac{(L - a)\ (2a^2 - La - L^2)}{4bt3} \quad \left(\frac{\Delta P}{\Delta y}\right)$$

where

L = span, in.

a = 1/2 span, in.

t = thickness, in.

b = width, in.

ΔP = load increment measured by load cell, lbs.

Δy = deflection increment at 1/4 span, in.

(8) Compute and report the actual test values, the normalized values, and the coefficients of variation as required in Sections 3.5. and 3.6.

4.10.4.6 Short Beam Shear. Short beam (interlaminar shear) will be determined in accordance with AMS-3894 with the following noted exceptions.

(1) Crosshead speed shall be 0.050 inches/minute.

(2) Five fabric specimens shall be tested in the warp direction at room temperature and five fabric specimens shall be tested in the warp direction at 350° ± 5°F.

(3) Five tape specimens shall be tested at room temperature and five tape specimens shall be tested at 350° ± 5°F.

(4) Procedural testing shall be in accordance wtih specification AMS 3894.

(5) The thermocouple shall be positioned within 1/2 inch of each specimen to be tested at 350° ± 5°F.

(6) The specimen length (fiber direction) shall be .600 ± .005 inch.

(7) Nominal specimen thickness is .080 inch, and will not vary more than .002 inch over its entire length or width.

(8) Flexure failures may occur when span to thickness ratio is not small enough to induce a shear stress failure. In such cases, lower span to thickness ratios will be required and may best be obtained by increased thickness.

(9) Crosshead must be stopped immediately after load begins to drop off so that a shear failure can be observed. Continued motion will result in flexural failure, masking the true result. Typical shear and flexure failures are shown in Figure 2. Flexure failures must be reported as such.

(10) Compute and report the actual test values, and the coefficients of variation as required in Sections 3.5 and 3.6.

4.11 Warranty Period. The warranty period shall be the same as the material shelf life. Should a material lot fail to meet the acceptance test criteria at a time subsequent to initial acceptance testing but prior to the shelf life expiration date (subject to 3.3.5), the remainder of the lot may be returned to the vendor for remuneration.

5.0 PREPARATION FOR DELIVERY

5.1 Packaging and Shipping

5.1.1 Tape. The prepreg material, together with its carrier tape, will be wound under tension on to rolls or spools having a minimum inner diameter of 8 inches. The back surface of the carrier or separator paper will be clean and contain no materials which may contaminate the prepreg. Protective flanges will be incorporated on the rolls. Unless specified on the purchase document, no roll shall contain less than 20 or more than 10 pounds of acceptable prepreg. Each roll will be individually sealed in a clear, moisture proof, plastic bag, and labeled as per 5.2.1. Units packed in the preceeding manner will be shipped in insulated containers capable of using solid CO_2 to keep material temperatures below 0°F during transit. Prepreg will be removed from shipping containers and immediately placed in 0°F (or below) storage.

5.1.2 Single yarn/tow. The prepreg yarn/tow will be wound under tension on to spools having a minimum outer diameter of 3 inches and length of approximately 10 inches. The winding will be in the form of continuous non-contacting layers of adjacent hoop windings of fiber bundles, each layer being separated from the previous one by a sheet of separator paper placed circumferentially on the spool. The outermost layer of prepreg will be covered by a separator sheet. Unless specified on the purchase document, no roll will contain more than 3 pounds of prepreg. Each roll will be individually sealed in a clear moisture proof plastic bag, and labeled as per 5.2.1. Units so packed will be shipped in accordance with Section 5.1.1.

5.1.3 Woven Fabric, Chopped Mat. Fabric and chopped mat will be packaged in accordance with the applicable purchase order. Unless specified on the purchase document, sheet size will be nominally 2 feet wide (fill) by 5 to 6 feet long (warp). Stacked sheets will be separated from one another with clean separator material as specified in 3.3.3.3 and the entire stack will be bound top and bottom with thick, protective cardboard or equivalent. The packages will be taped and sealed in a moisture proof, clear plastic bag and labeled in accordance with Section 5.2. Shipment will be as described in 5.1.1.

5.2 Marking

5.2.1 Bag and Core. The following information shall be attached to the core of each roll or spool, and for fabric/mat to the cardboard surface containing the prepreg, and shall be visible through the clear, moisture proof, plastic sealing bag:

(1) Manufacturers name, symbol

(2) Material type; resin, resin/catalyst lot number, fiber, and prepreg designation.

(3) Lot and roll number

(4) Material Quantity: Linear feet and weight, if tape
Weight and approximate footage, if yarn
Weight and approximate square footage, if fabric or mat

(5) Storage life expiration date at 0°F

(6) Label stating "CAUTION: STORE AT OR BELOW 0°F." or equivalent

5.2.2 Shipping Package. Each shipping container shall have attached a clearly visible document detailing:

(1) Manufacturers name, symbol

(2) Material Designation

(3) Material Quantity

(4) Date of Manufacture

(5) Martin Marietta Aerospace Purchase Order number

(6) Warranty expiration date of material when stored at 0°F

5.2.3 Warning Sign. Each shipping container shall have visible a colored sign stating "CAUTION: STORE AND SHIP AT OR BELOW 0°F." or equivalent.

6.0 NOTES

6.1 Purchase Order. The following information, when applicable, shall appear on the purchase order:

Fiber designation	3.1.1
Resin designation	3.2.3
Tape Width	3.3.2.2.3
Yarn Width	3.3.2.2.3
Fabric, Mat Width	3.3.2.2.3
Fabric Mechanical Properties	3.4.3.3.3
Mat Mechanical Properties	3.4.3.3.4
Prepreg Staging	4.10.3.7
Laminate Physical Properties	Table III
Quantity	

6.2 Prepreg Documentation. The following information as applicable, shall appear on documentation either accompanying the prepreg shipment or mailed under separate cover:

Fiber Property Certification	3.1.3
Fiber Surface Treatment	3.1.2
Fiber Test Results	4.10.1
Resin Certification	4.10.2
Yarn Property Certification	3.4.3.1
Test Report	4.3
Qualification Report	4.5.1
Acceptance Report	4.5.2
Statement of Certification	4.5.3
Cure Cycle	4.9.1
Infrared Spectrograph	4.10.3.8
Packing Data	5.2.1, 5.2.2

TABLE I. FIBER PROPERTIES

FIBER TYPE	ELASTIC MODULUS $E_t \sim 10^6$ psi		TENSILE STRENGTH σ_t (ultimate) $\sim 10^3$ psi		DENSITY $\rho \sim$ g/cc	
	Nominal	Minimum*	Nominal	Minimum*	Nominal	Minimum*
I	57	50	325	250	1.70	1.65
II	36	28	375	350	1.79	1.72
III	32	25	350	300	1.76	1.70
IV	74	70	250	220	1.96	1.91
V	74	70	250	220	1.95	1.91

* Minimum Individual Value

TABLE II. Prepreg Physical Requirements
Grade A (epoxy) Resin

PHYSICAL PROPERTY	REQUIREMENT				TEST METHOD
	PREPREG FORM				Referenced Paragraph
	Yarn	Tape	Fabric	Mat	
Non Fiber Solids (% by weight)	40 ±3	40 ±3	40 ±3	50 ±5	4.10.3.1
Resin Percent Flow (% by weight)	20 ±3	20 ±5	20 ±4	25 ±5	4.10.3.2
Volatile Content (% by weight)	2.0 MAX	2.0 MAX	2.0 MAX	2.0 MAX	4.10.3.3
Tack	Shall pass test as per				4.10.3.5
Drape	Shall pass test as per				4.10.3.6
Gelation	Shall be reported as per				4.10.3.4
Infrared Spectrograph	Shall be reported as per				4.10.3.8

TABLE III. Physical Properties Limits of Cured Prepregs.

Grade A (epoxy) Resin

Prepreg Type	Property	Unit	Fiber Type III	Fiber Type II	Fiber Type I	Fiber Type IV, V
Tape	t/ply	in.	.005-.006	.005-.006	.006-.007	.0045-.0050
	Fiber content	v/o	60-68	60-68	60-68	*
	Void content, max.	v/o	1.5	1.5	1.5	1.5
	Density	g/cc	1.57 ±.05	1.58 ±.05	1.63 ±.08	1.63 ±.05
Yarn	t/ply	in.	.005-.006	.005-.006	.006-.007	*
	Fiber content	v/o	60-68	60-68	60-68	*
	Void content, max.	v/o	1.5	1.5	1.5	1.5
	Density	g/cc	1.57 ±.05	1.58 ±.05	1.63 ±.08	1.65 ±.05
Fabric	t/ply	in.	*	*	*	*
	Fiber content	v/o	60-68	60-68	60-68	*
	Void content, max.	v/o	2.0	2.0	2.0	2.0
	Density	g/cc	1.58 ±.05	1.58 ±.05	1.63 ±.08	1.65 ±.05
Chopped Mat	t/ply	in.	*	*	*	*
	Fiber content	v/o	60-68	60-68	60-68	60-68
	Void content, max.	v/o	2.0	2.0	2.0	2.0
	Density	g/cc	1.56 ±.05	1.57 ±.05	1.63 ±.08	1.65 ±.05

* To be specified on Purchase Document

TABLE IV. Unidirectional Mechanical Properties of Flat Laminates Grade A (epoxy) Resin

Property	Temp. °F	Type III	Type II	Type I	Type IV, V	Max. Coef. of Varia-tion,%
		Min. Ave. Value*	Min. Ave. Value	Min. Ave. Value	Min. Ave. Value	
Strength - Tensile Longitudinal (10^3 psi)	RT*	190	190	100	80	7.5(1)
	350*	175	175	90	80	7.5(2)
Transverse	RT	4.5	4.5	4.0	4.5	10
	350	2.5	2.5	3.5	4.5	15
Strength - Flexural Longitudinal (10^3 psi)	RT	220	220	100	95	7.5
	350	170	170	95	95	10
Transverse	RT	7.4	7.4	6.0	5.0	10
	350	5.1	5.1	4.0	3.0	15
Modulus - Tensile Longitudinal (10^6 psi)	RT	18.0	19.0	28.0	37.0	7.5
	350	17.5	18.0	27.0	36.0	7.5
Transverse	RT	1.0	1.0	1.0	.5	7.5
	350	.5	.5	.5	.3	7.5
Modulus - Flexural Longitudinal (10^6 psi)	RT	17.5	17.5	26.0	34.0	7.5
	350	16.5	16.5	25.0	33.0	10
Transverse	RT	1.0	1.0	1.0	.6	10
	350	.6	.6	.9	.5	15
Interlaminar Shear (Short Beam Shear) (10^3 psi)	RT	14.0	9.0	7.0	6.0	10
	350	7.5	6.0	4.0	4.0	15

(1) Applicable to Types I, II and III. 10 for Type IV and V.
(2) Applicable to Types I, II and III. 15 for Type IV and V.

* RT - Test conducted at Room Temperature
* 350 - Test conducted at 350°F after a minimum 10 minute soak at 350°F.
* Min. Ave. Value - Minimum average value of 5 specimen tests.

TABLE V(a). Qualification Tests

Test	Requirement	Test Para.	Test Frequency	
			Tape, Yarn	Fabric, Mat
Cosmetics	3.3.2.2	3.3.2.2	Unit	Unit
Non Fiber Content	3.3.2.1	4.10.3.1	Unit	Lot
Resin Flow	3.3.2.1	4.10.3.2	Unit	Lot
Volatile Content	3.3.2.1	4.10.3.3	Unit	Lot
Gelation	3.3.2.1.	4.10.3.4	Unit	Lot
Tack	3.3.2.1	4.10.3.5	Unit	Lot
Drape	3.3.2.1	4.10.3.6	Unit	Lot
Infrared	3.3.2.1	4.10.3.8	Unit	Lot
Density	3.4.2.3	4.10.4.1	Laminate	Laminate
Fiber/Resin/Void	3.4.2.1	4.10.4.2	Laminate	Laminate
Thickness	3.4.2.2	4.10.4.3	Laminate	Laminate
0° Tension RT	3.4.3.3	4.10.4.5	Lot	Lot
0° Tension 350	3.4.3.3	4.10.4.5	Lot	Lot
90° Tension RT	3.4.3.3	4.10.4.5	Lot	Lot
90° Tension 350	3.4.3.3	4.10.4.5	Lot	Lot
0° Flex RT	3.4.3.3	4.10.4.6	Lot	Lot
0° Flex 350	3.4.3.3	4.10.4.6	Lot	Lot
90° Flex RT	3.4.3.3	4.10.4.6	Lot	Lot
90° Flex 350	3.4.3.3	4.10.4.6	Lot	Lot
0° SBS RT	3.4.3.3	4.10.4.7	Lot	Lot
0° SBS 350	3.4.3.3	4.10.4.7	Lot	Lot
90° SBS RT	3.4.3.3	4.10.4.7	N/A	Lot Fabric Only
90° SBS 350	3.4.3.3	4.10.4.7	N/A	Lot
Therm. Expan 0°, 90° dir. RT	3.4.2.6	3.4.2.6	Lot	Lot
Therm. Expan 0°, 90° dir. 350*	3.4.2.6	3.4.2.6	Lot	Lot
Fiber	Certification of Fiber properties required with Qualification tests in accordance with Para. 3.1.1 and 4.5.3			
Resin	Certification of Resin properties/tests required with Qualification tests in accordance with Para. 3.2 and 4.5.3			

* Test to be conducted by Martin Marietta Aerospace

TABLE V.(b) Acceptance Tests

Test		Requirement	Test Data	Test Frequency	
				Tape, Yarn	Fabric, Mat
Cosmetics		3.3.2.2	3.3.2.2	Unit	Unit
Non Fiber Content		3.3.2.1	4.10.3.1	Unit	Lot
Resin Flow		3.3.2.1.	4.10.3.2	Unit	Lot
Volatile Content		3.3.2.1	4.10.3.3	Unit	Lot
Gelation		3.3.2.1	4.10.3.4	Lot	Lot
Tack		3.3.2.1	4.10.3.5	Lot	Lot
Drape		3.3.2.1	4.10.3.6	Lot	Lot
Infrared		3.3.2.1	4.10.3.8	Lot	Lot
Density		3.4.2.3	4.10.4.1	Laminate	Laminate
Fiber/Resin/Void		3.4.2.1	4.10.4.2	Laminate	Laminate
Thickness		3.4.2.2	4.10.4.3	Laminate	Laminate
0° Flex	RT	3.4.3.3		Lot	Lot
	350	3.4.3.3		Lot	Lot
0° SBS	RT	3.4.3.3		Lot	Lot
	350	3.4.3.3		Lot	Lot
90° SBS	RT	3.4.3.3		N/A	Lot Fabric
	350	3.4.3.3		N/A	Lot Only
Fiber		Certification of fiber properties required with Acceptance tests in accordance with Para. 3.2 and 4.5.3			
Resin		Certification of Resin properties/tests required with Acceptance tests in accordance with Para. 3.2 and 4.5.3			

TABLE VI. Mechanical Test Specimen Requirements

Material Type	Specimen Geometry	PROPERTY DETERMINED		No. of Specimens Required Per Material Lot	
				RT	350
Tape	Flat	0° Tensile	σ,E,ε	5	5
		90° Tensile	σ,E,ε	5	5
		0° Flex	σ,E	5	5
		90° Flex	σ,E	5	5
		0° SBS	σ	5	5
Fabric	Flat	0°(Warp) Tensile	σ,E,ε	5	5
		90°(Fill) Tensile	σ,E,ε	5	5
		0°(Warp) Flex	σ,E	5	5
		90°(Fill) Flex	σ,E	5	5
		0°(Warp) SBS	σ	5	5
		90°(Warp) SBS	σ	5	5
Chopped Mat	Flat	0°(X dir.) Tensile	σ,E,ε	5	5
		90°(Y dir.) Tensile	σ,E ε	5	5
		0°(X dir.) Flex	σ,E	5	5
		90°(Y dir.) Flex	σ E	5	5
		0°(X dir.) SBS	σ	5	5
Yarn, Tow	Flat	Certify to unidirectional mechanical properties as per Table IV			

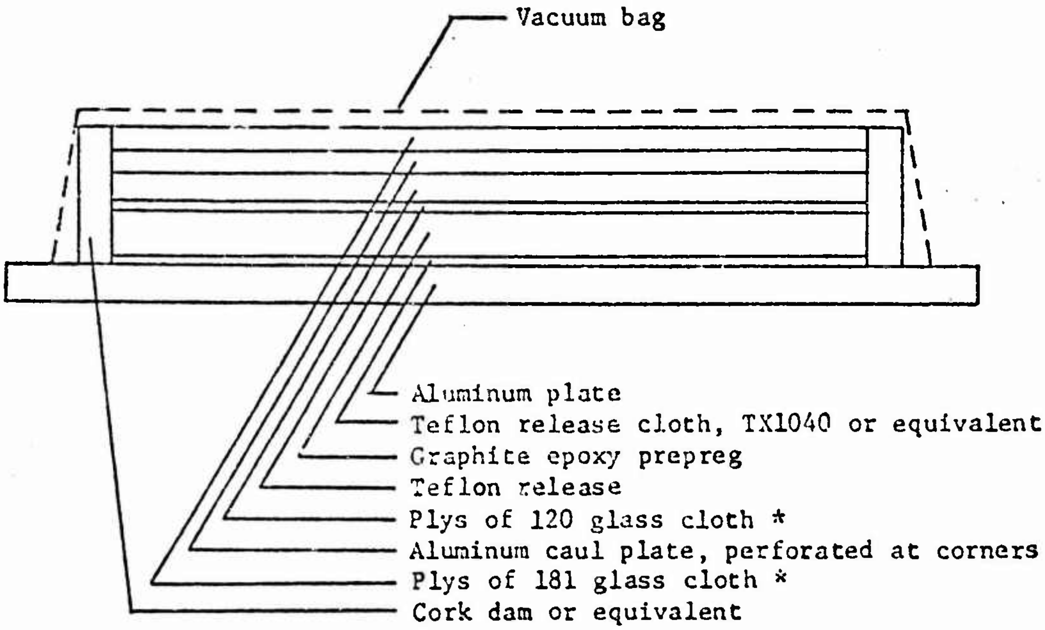
σ Ultimate stress, psi
ε Computed Ultimate Strain, μ in/in
E Elastic Modulus, psi
0° Fiber direction
90° Cross Fiber Direction

TABLE VII. Test Panel Fabrication for Mechanical Qualification - Acceptance Tests

(For Information Only)

Material Type	Mechanical Tests Tests	Approx. Panel Size	No. of Req'd. Panels for Qual.	No. of Req'd. Panels for Accp.
Tape	0°, 90° Flex, @ RT, 350 0° SBS, @ RT, 350	8" X 16" X .08"	1	1
	0° Tens, @ RT, 350	10" X 7" X .03"	1	
	90° Tens, @ RT, 350	10" X 12" X .08"	1	
Fabric, Mat	0°, 90° Flex, @ RT, 350 0°, 90° SBS, @ RT, 350	8" X 16" X .08"	1	1
	0° Tens, @ RT, 350 90° Tens, @ RT, 350	10" X 20" X .03"	1	
Yarn, Tow	*		*	*

* To be determined



* No. of plys of bleeder cloth dependent on No. of graphite plys; to be specified by vendor

NOTE: The layup procedure and cure cycle shall be specified by the prepreg vendor.

Figure 1. Layup for Prepregs (Optional)

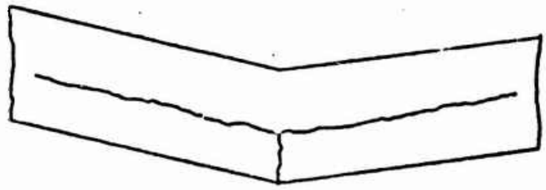


Figure 2A. Typical Interlaminar Shear

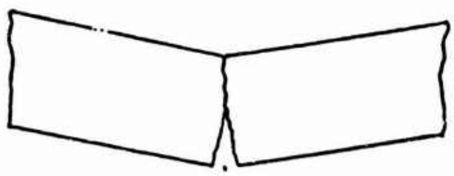


Figure 2B. Typical Flexural Failure

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EPOXY CONICAL SHELL DEVELOPMENT
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illus - tables, Contract DAAG46-76-C-0008
D/A Project 1W162113A661, AMCMS Code 612113.11.07000
Final Report, August 15, 1975 to November 1976

Key Words

Composite materials
Composite structures
Fiber composites
Graphite composites
Missile airframes
Missiles

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ULTRA-HIGH-MODULUS GRAPHITE/
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Technical Report AMMRC TR78-38, August 1978, 111 pp -
illus - tables, Contract DAAG46-76-C-0008
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